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A STUDY OF THE EFFECT OF FLIGHT DENSITY AND BACKGROUND NOISE ON V/STOL ACCEPTABILITY

by Harry Sternfeld, Jr., Ernest G. Hinterkeuser, Roy B. Hackman, and Jerry Davis

Prepared by
BOEING VERTOL COMPANY
Philadelphia, Pa. 19142
for Langley Research Center

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16. Abstract

A study was conducted in which test subjects evaluated the sounds of a helicopter, a turbofan STOL and a turbojet airplane while engaged in work and leisure activities. Exposure to a high repetitive density of the aircraft sounds did not make the individual sounds more annoying but did create an unacceptable environment. The application of a time duration term to dB(A) resulted in a measure which compared favorably with EPNL as a predictor of annoyance. Temporal variations in background noise level had no significant effect on the rated annoyance.

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NOTICE

All measurements and calculations in this report were originally in the U.S. Customary Units.

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By Harry Sternfeld, Jr.
and Ernest G. Hinterkeuser
Boeing Vertol Company

and Roy B. Hackman, PhD and Jerry Davis, PhD
Hackman and Associates

SUMMARY

A program was conducted, during which test subjects evaluated the sounds of a helicopter, a turbofan STOL, and a turbojet airplane. Over 10,000 evaluations were made while the subjects were engaged in work and leisure activities. The effect of number of flights per hour and types of background noises were evaluated. In addition a detailed study was made of the time patterning employed by test subjects in arriving at a noise evaluation, and some of the psychological factors which may influence response to aircraft noise and/or test programs.

Some of the important findings were:

1. Exposure to a high repetitive density of aircraft sounds does not make the individual sound more annoying, but the total exposure however, can create an unacceptable environment.

2. The inclusion of a time duration term applied to dBA measurement can result in a correlation with subjective response, which compares favorably with Effective Perceived Noise Level.

3. Temporal variations in ambient noise levels which do not mask the aircraft sounds have no significant effect on the evaluation of the aircraft noise.

4. The time during exposure to aircraft noise at which an evaluation is made has little effect on the evaluation.

INTRODUCTION

This program along with reference 1 and 2 forms a set of investigations to assist in developing evaluation methods, and limits, which can be applied to the noise generated by V/STOL aircraft operations. These type of aircraft require separate consideration from airplanes because of substantial differences in acoustical spectra, exposure times, and flight schedules. In addition since helicopters conduct terminal operations in center city and suburban locations the effect of ambient noise due to traffic may be quite influential on subjective assessments.

Obviously, the optimum criteria can be established by introduction of the particular service, studying the public response, and then setting the noise limits. This is in fact the noise case history of the jet airplane. It is apparent, however, that such procedures are no longer socially acceptable nor economically feasible, and that evaluations must be made a part of the planning and development cycle.

In a previous study conducted by Boeing-Vertol for NASA (ref. 1), the method of paired comparisons was used to evaluate the relative annoyance of the sounds of several types of V/STOL aircraft. In a second investigation (ref. 2) a test methodology was used which attempted to provide subjective evaluations of aircraft noise obtained under more natural conditions than the traditional laboratory tests. This method of "Absolute Subjective Testing" is based on the interaction between the individual and the effect of noise on his activities and still yields results which are interpretable in terms of criteria. This method was then used to study the effects of durations of noise exposure on subjective evaluation.

The concept of obtaining evaluations as affected by personal activity is of particular significance to the VTOL aircraft. Because of the ability of VTOL aircraft to hover and fly at extremely low speeds, the potential noise exposure to observers can be many times that resulting from a fly-over of a fixed wing airplane. In such situations it might be expected that the cumulative effects of increased time could be substantially different if the test subject is engaged in activities which absorb his interest, rather than merely sitting and listening to the sound. In the case of VTOL aircraft the evaluation of acceptable acoustical signatures can dictate the appropriateness of various configurations to serve the commercial market. It is therefore not inconceivable that an artificial conservatism in such an item as time exposure factor could prematurely discourage the development of VTOL aircraft service.

ABSOLUTE SUBJECTIVE RESPONSE TEST

DESCRIPTION OF PROGRAM

Concept

This program was designed to collect the subjective opinions regarding the acceptability of aircraft sounds and to correlate these evaluations with the acoustical environment. A major goal was to make the procedure as natural as possible so that the evaluation would be based on the manner and degree in which the noise affected the activities of the subject, and the act of performing the rating would become a secondary task. This is in contrast to another type of evaluation in which the subject offers opinions of how the sound might affect him in various situations and his primary task is listening to noise and filling out an evaluation sheet.

In order to achieve these goals, the test situation was designed to incorporate the following features:

1. The subjects were housed in a "normal" environment, and the sounds were generated from the exterior to the housing structure.

2. The subjects were engaged in activities which had significance to them, and the process of indicating their noise evaluations was designed to create a minimum distraction from these activities.

3. The time duration of the sounds and the time periods between, were representative of a range which might be expected to occur in commercial VTOL aircraft operations.

4. During a portion of the program the ambient, or background, noise consisted of recorded traffic noise of two different types instead of a quiet laboratory environment.

Test Facility

The test subjects were housed within a 8.5 x 3.0 x 2.1 m (28 x 10 x 7 ft) office trailer which was located within a 12.2 x 6.1 x 6.1 m (40 x 20 x 20 ft) acoustically isolated chamber. The trailer was of metal frame and skin construction with wood paneling for the interior walls. The floor was completely covered by a carpet. The interior of the trailer was furnished so that one half of it simulated a working environment with office tables and chairs, while the other half simulated a leisure environment with a couch, lounge chairs, a television set, tables, etc. No wall was used to separate the areas, in order to keep the general atmosphere as spacious as possible. Ventilation was accomplished by tying into the Acoustical Laboratory air conditioning system, thereby providing a pleasant climatic atmosphere without incurring noise levels which would be typical of window air conditioners.

Figure 1 illustrates the general arrangement, while Figure 2 shows test subjects in the work and leisure environments.

The aircraft sounds were played through a system whose speakers were located as shown in Figure 1. These speakers were mounted above the roof level of the trailer and directed at the trailer wall and roof. Figure 3 illustrates the acoustical systems used to generate the ambient and aircraft noises. The acoustical environment within the trailer was continuously monitored by recording the output for four calibrated microphones on a tape recorder (Figure 1).

In order to collect the subjective evaluations each test subject was equipped with a small box which contained nine pressure sensitive switches imbedded in a thin plastic card as illustrated in Figure 4. These switches were very easy to actuate in that they responded to extremely light finger pressure, had no perceptible motion, and were completely silent. The square format of the pushbutton arrangement was felt to be advantageous not only because of its compactness, but also because it did not have the obvious extreme psychological ends of an in-line check list. It was found that the test subjects rapidly learned to actuate this device with minimal distraction from their other activities.

The actuation of a given response box energized a digital indicator in the control room so that the corresponding numeral was displayed on a read-out indicator. Figure 5 shows a block diagram of the system and the monitor board display. The response data was recorded manually after the end of each test sound and was also recorded automatically every two seconds by a motion picture camera.

A digital clock on the monitor panel was synchronized with two identical clocks inside the trailer so that any observations made by the psychologist who was present in the trailer with the test subjects could be correlated with the response data.

Preparation of Test Sounds

Two configurations were selected for this study: a tandem rotor helicopter and a turbofan STOL. These configurations were selected partly because they embody the types of acoustical signatures which may be most important with respect to several of the configurations under consideration for inter- and intraurban transportation. More specifically, the tandem rotor helicoptor signature is also quite similar in spectral and temporal characteristics to the main rotor of a single rotor helicopter or to a tilt rotor configuration, while the turbofan STOL sound is more directly comparable with jet lift VTOLs and conventional airplanes.

The basic aircraft designs, noise predictions, and acoustical simulations were taken from those prepared under a previous NASA contract (ref. 1). The aircraft, which were essentially sized for 60 passengers and a 926 km (500 mile) range, are illustrated in Figures 6 and 7. Specific details regarding the prediction and simulation of these basic signatures can be found in the reference 1 report. These tapes were reworked using the systems illustrated in Figure 8 to achieve the required time durations, levels and spectrum shapes inside the test enclosure. Figures 9 and 10 illustrate the spectra and temporal characteristics of each signature.

In addition to these two VTOL configurations, the subjects were exposed to the fly-by noise of a jet airplane. The individual sounds were then combined, in random order on magnetic tape such that test sessions could be run with aircraft sounds occurring at rates of 6, 12, 24 and 48 sounds per hour.

Three background,or ambient sounds were used during the program. The first was low level, a broadband noise (which was also used in the ref. 2 study), approximating an NC-30 curve; the others were recorded traffic noise: one taken adjacent to a heavily travelled highway, and the other inside an office six floors above a major center city street (Broad Street, Philadelphia). The levels and spectra of these sounds are presented in Figure 11.

Test Subjects

The subjects in this program were twenty-two males and six females between the ages of twenty-one and thirty-four years. All subjects were members (or wives of members) of the Swarthmore-Wallingford Chapter of the Pennsylvania Jaycees, a young mens' community service organization. Since payment for their services was made directly to the organization and used for their community activities, the subjects were, in an indirect sense, volunteers. Their motivation was displayed by high attendance and cooperative attitude. Some of the males had been subjects during the ref. 2 program, the remainder were initially screened by means of audiograms for hearing, and by interviews with the psychologists, for attitude. Deviations of more than 20dB below the group mean at any point in the audiogram, or a negative attitude towards the test program, was considered justification for disqualification.

Prior to the program the subjects were instructed in their functions and the use of the response equipment, and a practice session was held. A verbatim copy of the instructions may be found in Appendix A.

Subjective Acceptability Tests

A typical test session consisted of one 2 hour and one 1 hour period. During the first period the subjects were located at the "work" end of the facility (Figure 2). They performed paperwork and reading activities which had been approved by the psychologists. In general, this work was directly related to the subjects full time occupation or avocation and was therefore similar to that he performed during the normal day. In this manner the tasks being performed were always meaningful to the subject, as opposed to an assigned work effort in which they felt no personal involvement.

The second period was generally spent in the more comfortably furnished end of the test room, although it was permissible for subjects to remain in the work area if this was more amenable to their leisure activity. During this time the most frequent activities were watching television, playing cards, conversations, and recreational reading. One of the psychologists was in the trailer with the subjects at all times in order to monitor activities and to act as a general observer.

The subjects had been instructed in the use of the response equipment, as previously described, and quickly learned to respond with a minimum amount of distraction. Periodically, as aircraft sounds were heard they indicated their responses and changed them as often as they desired by pushing a different button. There was no specific period of time at which an evaluation was demanded. The final evaluation for each sound, however, was assumed to be that which was indicated at 10 seconds after the end of the stimulus. At that time the data system automatically disconnected the individuals' response boxes from the indicator board while a final tally was made, and the indicator board was automatically reset to zero in preparation for the next stimulus.

The subjects were divided into four groups of males and one group of females. Table I summarizes the test program structure and Table II presents the exposure history of the group. The order of presentation was randomized in order to prevent the subjects from recognizing the test variables.

TABLE I

TEST PROGRAM OUTLINE

Test	Exposures per Hour	Test Sessions per Subject	Total Observations*	Background
1	6	2	900	Low Level Broad-band
2	12	1	900	↓
3	24	1	1,800	↓
4	48	1	3,600	↓
5	24	1	1,800	Highway
6	24	1	1,800	City Street
Total		7	10,800	

*Total Observations = (Exposures/Hr) × (Sessions/Subject) × (3 Hrs/Session) × (25 Subjects)

TABLE II

EXPOSURE HISTORY

(OBSERVATIONS)

	Work	Leisure	Total
Male	5760	2880	8,640
Female	1440	720	2,160
Total	7200	3600	10,800

DISCUSSION OF RESULTS

Correlation of Subjective Responses with Acoustical Data

The acoustical data recorded in the test environment was analyzed, and the results are presented along with mean subjective ratings in Figures 12-14. The subjective response data is further detailed in Appendix B, Table I.

Sound pressure levels on the dBA and dBC scales are maximum values attained during each sound. The Composite Perceived Noise Level (PNLC) was calculated using the method and tables of reference 3. In this case the composite value is obtained by using the maximum sound pressure level in each frequency octave band rather than calculations over many time increments. Effective Perceived Noise Level (EPNL) was calculated from 1/2 second interval 1/3 octave band data in accordance with reference 4.

The data reported is that obtained from the microphone located on the work table closest to the center of the test room. Levels varied somewhat with location of the microphone and with the physical locations of the test subjects. Checks of other microphones and various personnel arrangements showed a non-systematic variation of up to plus or minus 2dB.

The subjective data used for comparison combined the responses for male and female observers and both leisure and work environments. This was done because although there were differences in response patterns between the male and female group, these were not significantly greater than the range of responses within one sex group. Furthermore any differences that may exist do not justify the elimination of either group from the data.

Figures 12 through 14 presents the correlations of subjective response with several standard measurements of the acoustical environment. An extremely high degree of corre - lation is afforded with either aircraft, regardless of the measure employed.

Due to the different temporal patterns inherent in the mode of operation of helicopters, as compared with STOL aircraft, (the helicopter has a significantly shorter duration of levels within 10 dB of the peak) the time correction inherent in the EPNL measure further collapses the data between the two aircraft. It is interesting to note that if the correction:

$$10 \log \frac{t}{15}$$

where t is the time, in seconds between the 10 dB down points, is applied to the A weighted sound pressure level (Figure 12) a similarly good correlation can be obtained using a much simpler analysis system which avoids the use of 1/2 second sampling and a digital computer.

The continuity of the results of this program with that of reference 2 is clearly illustrated in Figure 15. The data which is directly comparable in both programs is helicopter noise at a rate of 24 flights/hr with "NC-30" ambient, and observation by male subjects only.

Effect of Flight Density

An important inconsistency in the data was evidenced by the fact that the test participants spontaneously complained about the test sessions during which a rate of 48 exposures per hour was used although the ratings of individual sounds did not appear to be influenced.

Since there were no similar complaints about the 24 events per hour sessions, and since there had been no adverse comments during the reference 2 program, which involved 16 weeks of exposure at a rate of 24/hour, it was concluded that, the total noise exposure reached an unacceptable level when the exposure rate was in excess of that due to a test session of 24 flights per hour and less than 48 flights per hour.

The failure to provide this information by means of their individual rating selectors probably reflects a combination of a flaw in the construction of the experiment combined with strict adherence to instructions on the part of the test subjects. In effect they were asked to rate each sound as it was presented to them and this is precisely what they did. They reported the dual information that a high repetitive density does not make the sounds individually more annoying but the total exposure however, can create an unacceptable environment. Recognizing that problem in data interpretation existed, the question of frequency of occurrence was further investigated by means of a questionnaire which was conducted after the main program. These results, which generally support the above conclusions, are discussed more fully in a later section of this report.

In order to quantify the noise exposure limits expressed by the subjects, a rating method which combines events is required. Although this element is contained in the Composite Noise Rating and Noise Exposure Forecast methods, it was felt that a better mathematical modeling of the test program can be performed by the application of the Noise Pollution Level concept formulated by D. W. Robinson in reference 5.

The general concept formulated is that aircraft noise will be judged on the basis of the amount by which it increases the existing Noise Pollution Level according to the formula:

$$\Delta_{NP} = K\left[\frac{1}{t_o}\int_{t_1}^{t_2}\left[L(t) - L_o\right]^2 dt\right]^{1/2}$$

where

Δ_{NP} = Increase in noise pollution level

K = A constant whose value depends on the noise measurement units used

t_o = Total time being evaluated

t_1 & t_2 = Start time and end time of aircraft noise event

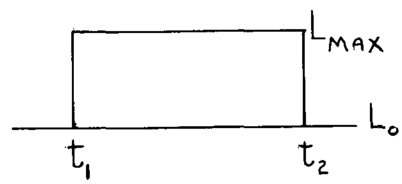
$L(t)$ = Noise due to aircraft

L_o = Ambient noise

The noise pollution increase due to a series of aircraft noises in elapsed time t_o can be obtained by summing individual Δ_{NP}'s.

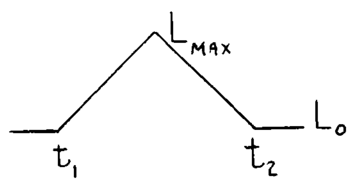
Most aircraft flyovers can be constructed from a combination of rectangular and triangular time historys:

For the rectangular history



$$\Delta_{NP} = K(L_{MAX} - L_o)\sqrt{(t_2 - t_1)/t_o}$$

For the triangular history



$$\Delta_{NP} = K(L_{MAX} - L_o)\sqrt{(t_2 - t_1)/3t_o}$$

Any desired set of noise measuring units can be used for calculating L_{NP}. However, PNL_T will be used for this study in order to provide for tone corrections, which are not available for A Weighted Sound Pressure Level data. Appendix C contains the Noise Pollution Level calculations for each test session which was conducted as part of this program.

Robinson's argument is, that the noise due to an aircraft operation will be judged on the basis of the amount by which it increases the existing ambient Noise Pollution Level. Figure 16 shows this increase for each test session and indicates that, with the low level "NC-30" ambient, an increase of greater than approximately 20 and less than about 30 L_{NP} was permissible.

Note that the rate of increase of noise pollution level is somewhat more critical than the 3dB per doubling implied by constant energy concepts employed in Noise Exposure Forecast and Composite Noise Rating and, in fact, becomes very steep as the noise fills the entire time span. That is because L_{NP} considered not only the time of aircraft noise exposure, but also the portion of total time that it comprises. It is also noted that the tolerance level determined by this experiment is greater than the 10 units suggested by the reference 5 paper and probably reflects a more realistic assessment of what can be expected in a community where people are engaged in activities which divert their primary attention from the aircraft itself.

Effect of Background Noise

The testing at a rate of 24 samples per hour was repeated using the background noises described in the section on Tape Preparation. They were intended to provide a more realistic ambient such as might be encountered inside well constructed buildings adjacent to city streets and/or highways. The change in sound from the broad-band sample used in this portion of the program was characterized by a type of background noise which embodied a higher degree of variation due to changes in traffic flow. Figure 11 shows a graphic display of the different ambients. The ambient levels were kept in a range where actual acoustical masking was not expected in order to avoid confusion between the effect of background noise variation on subjective evaluation and the ability of the subjects to hear the aircraft.

The test results (Appendix B Table I) indicate that the variation in low level background noise had no significant effect on annoyance , although there were nine cases of increased mean group rating compared with five decreases, with none of the differences as large as one full rating unit. As discussed in the reference 2 report of experiments using the same rating devices and systems, a step of about three units was required to provide clearly significant separations in decision. This conclusion was further substantiated by Paired Comparison Testing employing different ambient noises which will be discussed more fully in a following section, (page number 15).

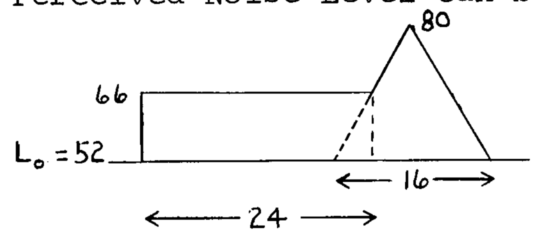
It should not be concluded from the above results that background noise can not be an important factor in determining the annoyance due to aircraft operation, but only that changes in the temporal characteristic of ambients whose levels are considerably lower than the aircraft noise levels are evidently not important. This situation is likely to exist very close to the terminal itself, while at greater distances the aircraft and traffic levels will probably be more balanced.

IMPACT OF NOISE PARAMETERS ON DESIGN AND OPERATION

The effect of meeting the noise constraints developed in the preceding section can be demonstrated by application to a selected model as follows:

Assuming a terminal 152.4 m (500 ft) distant from a building with low ambient noise comparable to that of the experimental program (52 PNdB). Evaluate the effect of operation of a modern 50 passenger tandem rotor helicopter (Boeing-Vertol Model 347):

From flight data, corrected to indoor valves, the time history of Perceived Noise Level can be constructed as shown:



The increase in Noise Pollution Level due to introducing the helicopter operation can then be calculated as follows:

$$\Delta L_{NP} = \sqrt{VN}$$

where

$$V = \left[K(80-52)\right]^2 \left[\frac{16}{3(3600)}\right] + \left[K(66-52)\right]^2 \left[\frac{24}{3600}\right]$$

N = Number of flights per hour (3600 seconds)

Applying the value of k=2.56 for units in Perceived Noise Level (ref. 5):

$$\Delta L_{NP} = \sqrt{16.17\,N}\ \text{PNdB}$$

In order to extend the investigation to other size helicopters the data of Figure 17 was collected and shows a direct linear relationship between gross weight and passenger capacity of commercial helicopter designs.

Since first approximations of rotational noise and vortex noise (reference 6) both follow a 6dB per Doubling of thrust trend for constant tip speed, 6dB per Doubling of passengers will be used for this study, yielding:

For 100 passengers

$$\Delta L_{NP} = \sqrt{28.7\,N}$$

For 25 passengers

$$\Delta L_{NP} = \sqrt{7.52\,N}$$

Figure 18 shows the resulting information superimposed with lines of constant passenger per hour capacity. From this it can be concluded that for the illustrative case chosen the larger number of flights with smaller aircraft displays a slight advantage, and that 1600 passengers/hour lies in the upper range of subjective limits as determined by the psycho-acoustic testing. In order to increase service still further, additional terminal sites in the area would be required.

The effect of flight trajectory is shown in Figure 19, which uses an additional set of data obtained by employing different departure paths to further alter noise exposure on the ground.

The above examples are illustrative of the manner in which the subjective limits can be applied to design studies or to comparative configuration analyses. The results apply only to the cases shown and are not necessarily general. Obviously, other noise reduction techniques, such as tip speed change, or rotor redesigns would yield still different results as would other configurations.

VARIATION OF SUBJECTIVE RESPONSE WITH EXPOSURE TIME

One of the primary objectives of the reference 2 program, was the investigation of the effect of the duration of V/STOL aircraft sounds on subjective response. This factor is extremely important with respect to these particular configurations, because of the relatively long time which can be encountered compared with CTOL aircraft due to hover. The results of that program did, in fact, demonstrate that, the time corrections applied in calculating Effective Perceived Noise Level are not linear with the length of exposure.

The program however, did not permit examination of at what points during the noise exposure the decision process takes place. Since a deeper understanding of this factor could lead to better planning of aircraft operations, this data was reexamined by detailed reading of the motion pictures, which had been taken of the monitor boards during the reference 2 program.

The results of this study are presented in Table II Appendix B, and shown in Figures 20 and 21 : For short sounds (below thirty seconds) there is one evaluation made and this occurs shortly after the end of the sound. As the time of the sound exposure increases there is an initial judgment and then often a second evaluation. Rarely were more than two evaluations made during the course of a single sound. Most judgments of the longer sounds however, were completed before the end of the sound, and in fact, before the sound reached its peak value.

Figure 21 indicates however, that the time in the noise event at which the evaluation is made has no consistent effect on the evaluation itself. In other words, if a judgment is made before the peak is reached, an experienced observer evidently prejudges the level which will be attained based on the earlier portion of the noise.

Since persons living in the vicinity of airports tend to become calibrated to aircraft noise, and also become experienced observers, it is likely that the response to flyover noise will be set during the approach and that the actual peak level merely confirms the earlier reaction. It may, therefore, be argued that the time during which a person is annoyed by aircraft noise may initiate when he realizes that the sound will become loud and continues as long as his suspicion appears to be confirmed.

STUDY OF INDIVIDUAL FACTORS IN ANNOYANCE EVALUATION

PAIRED COMPARISON STUDIES

The purpose of these studies was to investigate the following: (1) Relative annoyance of aircraft sounds when the two types of traffic noise presented in Figure 11 were also present; (2) Relative frequency of descriptive terms used by the observers, when they reported that they were, in fact, annoyed.

The tests were conducted in the same trailer used for the Subjective Acceptability Tests and utilized recordings from this program and from the ref. 2 program as comparative elements.

The arrangement of the sounds was such that comparison sound A was followed by test sound B, which was in turn followed by the same comparison sound A (repeated). This variation of counter-balanced order was intended to reduce or eliminate the position effect which is very bothersome in the use of paired comparisons. In all instances, the middle sound was the test sound which was to be judged as more annoying or less annoying than the two comparison sounds which were identical.

The instructions to the subjects are shown in Appendix D. Part I refers to the stimulus sound, Part II refers to the response (degree of annoyance) and Part III refers to the description of the test sound. The instructions for the paired-comparisons test (Part I) were read to the observers as they read them silently. Questions were invited and discussed, followed by several practice exercises. It will be noted that in Part II the observer was instructed to make the paired-comparison first, and then rate the difference between the test sound and the comparison sound. The observer was permitted to judge the two sounds as equally annoying, if he so desired. This modified and improved paired comparison procedure enabled the experimenters to measure both the proportionality and direction of the paired judgments, as well as the intensity or strength of the annoyance associated with the judgment.

Part III of the instructions and procedure consisted of two parts: In the first part the observer was asked to underline those words that described the test sound; he could also make comments. In the second part, the observer was asked to underline those words which helped describe how he felt about the test sound, he could also make comments.

Effect of Added Noise

In this test, the test sound (B) used the same aircraft sound as the comparison sounds (A) except that each test sound had an added background of the city or highway traffic noise while the comparison sound used the "NC-30" background noise. As shown in Table III of Appendix B a large portion of the test subjects regarded the sounds to be of equal annoyance regardless of the background sound.

The following table III, reveals results which are highly consistent with the information obtained during the

TABLE III

PAIRED COMPARISON TESTS
MEAN ANNOYANCE RATING

Aircraft		Added Noise Aircraft Level I City	Added Noise Aircraft Level I Highway	Added Noise Aircraft Level II City	Added Noise Aircraft Level II Highway
Jet Reference	$\bar{x}$	2.96	3.01	3.03	3.05
	σ_x	0.33	0.32	0.34	0.25
Helicopter	$\bar{x}$	3.25	3.26	3.32	3.50
	σ_x	0.50	0.42	0.41	0.59
Turbofan	$\bar{x}$	3.20	3.18	2.99	3.19
	σ_x	0.34	0.59	0.43	0.35
Tilt Wing	$\bar{x}$	3.11	3.49	2.96	3.25
	σ_x	0.28	0.51	0.41	0.43
Combined	$\bar{x}$	3.13	3.23	3.07	3.25
	σ_x	0.36	0.46	0.40	0.40

ANNOYANCE SCALE

1	2	3	4	5
Much Less Annoying	Less Annoying	Equally Annoying	More Annoying	Much More Annoying

Range of Ratings

NOTE: $\bar{x}$ represents an arithmetic mean absolute subjective testing, in that the effect of adding low level noise with greater temporal variation again appears to have a small effect towards increasing subjective annoyance.

Descriptions of Annoying Sounds

In order to provide further insight into the elements which are important in developing ratings for V/STOL type sounds it was considered desirable to assess the characteristics of the sounds which annoy the subjects. In this test the comparison sounds consisted of various combinations of the following aircraft: helicopter, tilt wing, turbofan STOL, and jet airplane.

As previously described, the subjects not only made their comparative noise evaluations but also described their feelings about the test sounds as well as their descriptions of the sounds themselves.

From the selection of description of feeling (e.g. annoyed, irritated, pleasant), each answer was categorized as being acceptable or unacceptable to the test subject. Of those sounds judged unacceptable, the descriptions of the sounds were tabulated and are presented in Table IV.

TABLE IV

MOST FREQUENTLY USED WORDS TO DESCRIBE SOUNDS WHICH OBSERVERS REPORTED TO BE ANNOYING TO THEM

Aircraft	Sound Description	% of Times Description was Used
Helicopter (VTOL)	Rumbling Thundering	50% 24%
Tilt Wing (VTOL)	Resonant Rumbling	37% 31%
Turbofan (STOL)	Roaring Piercing Whining Loud	37% 26% 22% 22%
Jet Airplane (CTOL)	Roaring Powerful Loud Piercing	61% 33% 33% 26%

Note that for the two VTOL aircraft the descriptions indicate that annoyance, when it occurs, is associated with sounds which are predominated by low frequencies. This is not illogical since "thundering and rumbling" sounds are often associated with unpleasant aspects of the environment, such as danger.

From acoustical considerations it is important to note that the weighting of low frequency range is often minimized by many conventional noise rating measures and may warrant special consideration in evaluating public response to these types of aircraft.

PSYCHOLOGICAL FACTORS IN ANNOYANCE

In order to gain additional insight into some of the underlying reasons and motivations which may affect how the subjects respond to the aircraft noise stimuli, three procedures were employed:

I. Annoyance Survey to determine a general annoyance level for each participant.

II. Opinion Questionnaire to obtain information regarding how people generally react to aircraft noise under certain conditions.

III. Discussion Group to learn more about the subjects and their reaction to the study.

The most significant findings were:

1. The subjects were not found to be highly annoyed psychologically nor were they completely tolerant of their environment.

2. The subjects did not appear to have any psychological biases regarding environmental noise.

3. All of the subjects had traveled by air prior to this investigation and generally enjoyed air travel.

4. The subjects reported that they were more annoyed by sound components typical of jet aircraft than by sounds typical of other aircraft included in this research.

5. The subjects reported they were significantly more annoyed as the number of aircraft sounds increased in a given hour with indications that a rate of 48 per hour was unacceptable.

6. The subjects agreed that, during the experiment the aircraft sounds were considerably more annoying during the work period than during the leisure period. When engaged in non-work activities, they felt that interference with activities involving communication, such as talking or listening to the radio, was also affected.

Annoyance Survey

To determine a general annoyance factor for each participant in this study, an Annoyance Survey instrument (see Appendix E) was administered to each subject at the beginning of the investigation. The instrument contained 110 statements, 30 of which were defined as "environmental noise" statements (e.g., to hear a low-flying jet overhead). Eighty (80) statements were defined as "non-noise" items (e.g., to find hair in my food). Each subject recorded his "annoyance reaction" to each of the 110 statements by writing a number (1 to 9, with 9 being most annoying) after each item. The 1-9 scale was selected since the subjects were to utilize this same scale for recording their subjective responses to aircraft noise.

The results of this survey are summarized in Figure 22. As can be seen by inspection, the degree of uniformity exhibited by the scatter plot indicates no serious discrepancies between attitude toward noise and attitude toward other general types of annoyance, in fact the correlation between the two types of annoyance was +.78.

This high correlation is a most important finding. If the subjects had indicated significantly more (or less) annoyance for the "environmental noise" items, the data regarding their subjective responses to aircraft noise would have been suspect, as the subjects may have had prior psychological biases regarding environmental noise.

Although the consistency of the responses are highly significant, the relative homogeneity of the results with respect to the annoyance survey responses, did not permit a correlation analysis between the annoyance survey results and the absolute subjective test results.

The distribution of responses of the females was more heterogeneous than that of the males, thereby indicating the possibility of sex differences in response to the noise stimuli or to the test situation. Inclusion of both groups in the data appears to be legitimate, since the total group of female responses is consistent with the trend line male responses. inclusion of both groups in the data appears to be legitimate.

Opinion Questionnaire

An Opinion Questionnaire (see Appendix F) was completed by each subject at the conclusion of the testing program to obtain information regarding how people generally react to aircraft noise under various conditions. The major conclusions drawn from the data were as follows:

1. Subjects reported that they are very annoyed (7.0 or more on the 1-9 scale) by sounds described as: piercing; crashing; shrill; startling; blaring; screeching; harsh; shrieking and penetrating. It is noteworthy that these sounds are not the same ones which were indicated as being associated with annoyance due to V/STOL operation during the paired comparison testing. This indicates that the types of sounds made by V/STOL aircraft generally are not those which people find most objectionable.

2. Both male and female subjects reported that they are very annoyed by loud aircraft sounds when the aircraft is: On ground-testing engines; hovering overhead; taking off and landing. Since the first of the above involved noise while not in flight, while the other two may also involve psychological factors such as fear or anxiety, the separation of noise and emotional factors remains unclear.

3. The subjects reported that they are significantly more annoyed as the number of aircraft sounds increased in a given hour (see Table V). This finding would seem to be very important, since the subjective ratings of the aircraft sounds by the observers did not reflect significant increases when the frequency of aircraft sounds per hour increased. It would appear that subjects rated a given stimulus (i.e., aircraft noise) as independent judgments, with little or no regard to how often the sounds were occurring. When asked to provide additional information, however,

regarding their overall reactions, they did report that they were significantly more annoyed as the number of occurrences increased per hour.

In order to ensure that the subjects were not merely following a progressive scale, a second survey was given to another group in which the frequencys 1, 2, 4, 6, 12 times per hour were used. Shifting 6 and 12 from their original positions to the high end of the list resulted in approximately one unit rating increase, indicating satisfactory reliability.

4. The subjects reported that they are highly annoyed by loud aircraft sounds when engaged in the following activites: carrying on a conversation; watching television; or listening to the radio They indicated significantly less annoyance to loud aircraft sounds when: doing household chores; playing games indoors; engaging in hobbies. These results would suggest that ones reaction to an aircraft noise will vary significantly, depending upon the nature of the activity in which one is engaged. It seems aircraft sounds that interfere with communication are more annoying than aircraft sounds that occur while people are engaged in activities which do not require verbal communication.

TABLE V

Subjective Ratings of Aircraft Noise According to Frequency of Occurrence
(Results from Hackman-Davis Opinion Questionnaire)

Frequency	$\bar{x}$ Males	$\bar{x}$ Females
Less than once per hour	2.40	1.00
About 6 per hour	2.59	2.80
About 12 per hour	6.18	4.40
About 24 per hour	7.53	6.40
About 48 per hour	8.41	8.20

NOTE: $\bar{x}$ represents an arithmetic mean

Discussion Groups

The psychologists who conducted the experimental sessions also had a group discussion with the subjects at the conclusion of the investigation in order to learn more about the subjects and their reactions. The most important findings, upon analyzing the tapes of the discussions, were as follows:

1. All of the subjects stated that they had traveled in aircraft and generally enjoyed the experience.

2. The subjects expressed confidence with respect to the competency of pilots and in the general safety of air travel.

3. Both male and female subjects agreed that they were very annoyed during the testing sessions when numerous aircraft sounds occurred during each hour, especially 48 per hour.

4. Some subjects felt that some aircraft sounds were more annoying during the work period than during the leisure period.

CONCLUSIONS

As a result of the psychoacoustic testing, and associated studies which were conducted, the following conclusions can be drawn:

1. The procedure of obtaining evaluation of aircraft noise while the test subjects are engaged in other, more normal activities is desirable in order to avoid overconservative responses. It is recommended however, that evaluations of each separate noise event should be supplemented by more general evaluations of each test session in order to gain insight into the cumulative effects of combinations of separate noise events.

2. Exposure to a series of sounds at high repetitive density does not make those sounds, which occur later in the exposure period individually more annoying, even though the total noise exposure of combined events may become unacceptable.

3. The inclusion of time duration, as well as a measure of sound pressure level, is necessary in evaluating V/STOL aircraft noise.

4. Changes in the temporal qualities of a background noise whose levels are substantially below those of the aircraft noise appear to have no significant effect on the aircraft noise evaluation. Testing with different relative aircraft and background noise levels should be conducted.

5. When exposed to aircraft sounds of long duration, people tend to prejudge their final responses. The experienced observer, however, appears to have this ability and does not tend to revise his opinion after exposure to the entire sound which may contain higher levels than those heard at the time of judgment.

6. When they are annoyed by V/STOL sounds people tend to describe them by such terms as thundering, rumbling and roaring. These are low frequency descriptions which tend to be associated with unpleasant aspects of the natural environment (e.g. thunder, earthquakes, etc.).

7. The subjects were most annoyed by the aircraft sounds when they interfered with concentration during the work periods. However, when engaged in non-work activities, they felt that interference with communication, i.e. talking and listening, was also important.

The Boeing Vertol Company
Philadelphia, Pa.
September 28, 1973

APPENDIX A

INSTRUCTIONS TO TEST SUBJECTS

This Appendix contains instructions to the test subjects (twenty-two males and six females) regarding their functions for the three hour period and the use of the response equipment.

APPENDIX A

INSTRUCTIONS TO TEST SUBJECTS

1. During the next three hours, you will be involved in a study regarding the subjective acceptability of aircraft noise.

   a) The first two hours are defined as a "work" period. Bring your own work with you. Examples: writing technical reports or papers, research, professional study, preparing for tests, etc.

   b) The third hour is defined as a "leisure" period. Such activities as watching television, playing cards, conversation, or recreational reading are suitable.

2. You will be hearing a variety of aircraft sounds during the evening. Your primary task is to record your reactions to each sound you hear on the instrument in front of you.

3. Note the color of the instrument. You are expected to use the same instrument throughout the three hour period. Also, note the various colored electrical outlets in the room. It is essential that you match the color of your instrument with the color of the outlet.

4. You will also notice that your recording instrument has nine numbers, arranged in three rows. Record your reaction by pushing a number from one (#1) to nine (#9).

   a) For example, push number one, two or three (bottom row) when the sound you hear is in an acceptable or non-annoying range.

      #1 is least annoying on the scale.

   b) Or, push number seven, eight or nine (top row) when the sound is in an annoying or irritating range.

      #9 is most annoying on the scale.

   c) Further, push number four, five or six (middle row) when the sound you hear is in a moderately annoying range.

d) Each time, push the button you choose firmly and hold it for a few seconds.

5. If you decide to change your response during the sound or immediately afterward, you may do so by pressing another number. The last number you push is the one recorded by the monitor.

Any Questions?

Note: The psychologist who was acting as the test administrator at the time read the instructions to the **subjects** at the beginning of the experiment and whenever necessary afterwards. He demonstrated the use of the apparatus and checked whether the responses were being recorded on the monitor. Also at the beginning of each session, each observer pressed each button on his instrument in order to check whether or not the response was being shown on the monitor. The test administrator in the trailer was in direct telephonic communication with the technician in the separate electronics laboratory, so that immediate steps could be taken to correct any errors in the recording system at any time.

APPENDIX B

STATISTICAL TABLES

This Appendix contains three statistical tables:

Table I	-	Subjective Response Data
Table II	-	Variation of Subjective Response with Exposure Time
Table III	-	Results of Paired Comparison Test for Added Noise

The following symbols are used throughout:

N	=	Number of responses
$\bar{x}$	=	Mean subjective response
$\sigma_{\bar{x}}$	=	Standard deviation of responses
$\bar{t}$	=	Mean response time
σ_t	=	Standard deviation of response time

NOTE: $\bar{x}$ and $\bar{t}$ represent arithmetic means.

APPENDIX B

TABLE I

SUBJECTIVE RESPONSE DATA

ANNOYANCE RATINGS*
COMBINED WORK AND LEISURE
ALL TEST SUBJECTS

AIRCRAFT LEVEL		"NC-30" NOISE RATE PER HOUR 6	12	24	48	ADDED NOISE (24 PER HOUR) CITY NOISE	HIGHWAY NOISE
Helicopter Level - 3	N	89	116	167	345	172	166
	$\bar{x}$	1.89	1.39	1.62	1.50	1.98	2.48
	σ_x	.81	.89	.87	.72	1.18	1.58
Helicopter Level - 2	N	107	134	229	452	242	215
	$\bar{x}$	3.29	3.42	4.13	3.64	4.06	4.01
	σ_x	1.25	1.51	1.46	1.40	1.60	1.62
Helicopter Level - 1	N	119	141	262	509	258	242
	$\bar{x}$	5.47	5.46	6.40	5.69	6.58	6.50
	σ_x	2.05	2.11	1.64	1.85	2.11	1.86
Turbofan Level - 3	N	102	132	220	432	163	216
	$\bar{x}$	3.46	2.65	2.98	3.21	3.09	3.42
	σ_x	1.34	2.30	1.47	1.57	1.39	1.63
Turbofan Level - 2	N	110	125	230	4.79	237	245
	$\bar{x}$	4.51	4.33	4.79	5.00	5.04	5.38
	σ_x	1.32	1.68	1.12	1.52	1.56	1.74
Turbofan Level - 1	N	119	140	264	538	258	254
	$\bar{x}$	7.55	7.66	8.14	8.02	7.69	8.12
	σ_x	2.53	2.01	1.02	1.41	1.93	1.51
Jet	N	288	145	142	143	145	134
	$\bar{x}$	7.35	7.21	8.05	7.68	7.94	8.11
	σ_x	1.74	1.89	1.12	1.17	1.54	.99

*Weighted Averages

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TABLE II

VARIATION OF SUBJECTIVE RESPONSE WITH EXPOSURE TIME

Aircraft Type	Sound Duration Sec.	Level		Response	Changed Response
Helicopter	15	I	N	44	
			$\bar{t}$	22.80	
			σ_t	23.10	<10%
			$\bar{x}$	5.91	
			σ_x	1.91	
		II	N	40	
			$\bar{t}$	21.80	
			σ_t	25.20	10%
			$\bar{x}$	1.60	
			σ_x	1.20	
Helicopter	30	I	N	43	
			$\bar{t}$	32.23	
			σ_t	12.65	<10%
			$\bar{x}$	6.28	
			σ_x	1.31	
		II	N	37	
			$\bar{t}$	31.84	
			σ_t	9.03	
			$\bar{x}$	1.68	
			σ_x	1.13	
Helicopter	60	I	N	44	
			$\bar{t}$	50.95	
			σ_t	3.58	<10%
			$\bar{x}$	5.09	
			σ_x	1.49	

APPENDIX B

Aircraft Type	Sound Duration Sec.	Level	Response	Changed Response
		II N	39	
		$\bar{t}$	47.79	
		σ_t	16.27	
		$\bar{x}$	1.97	
		σ_x	1.03	
Helicopter	120	I N	42	N 13
		$\bar{t}$	68.45	$\bar{t}$ 90.76
		σ_t	39.49	σ_t 26.75
		$\bar{x}$	4.95	$\bar{x}$ 5.53
		σ_x	1.47	σ_x 1.42
		II N	34	N 7
		$\bar{t}$	62.35	$\bar{t}$ 103.85
		σ_t	39.14	σ_t 32.89
		$\bar{x}$	2.21	$\bar{x}$ 2.00
		σ_x	1.24	σ_x .54
	240	I N	44	N 19
		$\bar{t}$	103.09	$\bar{t}$ 188.79
		σ_t	80.16	σ_t 58.64
		$\bar{x}$	4.00	$\bar{x}$ 5.47
		σ_x	1.58	σ_x 1.54
		II N	35	N 8
		$\bar{t}$	98.06	$\bar{t}$ 211.25
		σ_t	81.93	σ_t 28.71
		$\bar{x}$	2.30	$\bar{x}$ 3.25
		σ_x	1.18	σ_x 1.09
Tilt Wing	15	I N	27	
		$\bar{t}$	21.40	
		σ_t	9.44	$<10\%$
		$\bar{x}$	6.07	
		σ_x	1.80	

APPENDIX B

Aircraft Type	Sound Duration Sec.	Level	Response	Changed Response
		II N	30	
		$\bar{t}$	24.43	
		σ_t	9.34	
		$\bar{x}$	2.17	
		σ_x	1.09	
Tilt Wing	30	I N	39	
		$\bar{t}$	34.02	
		σ_t	10.14	
		$\bar{x}$	6.13	
		σ_x	1.73	$< 10\%$
		II N	38	
		$\bar{t}$	38.94	
		σ_t	12.92	
		$\bar{x}$	2.95	
		σ_x	1.60	
Tilt Wing	60	I N	33	
		$\bar{t}$	38.48	
		σ_t	17.26	
		$\bar{x}$	6.27	
		σ_x	1.58	$< 10\%$
		II N	28	
		$\bar{t}$	41.18	
		σ_t	17.02	
		$\bar{x}$	2.64	
		σ_x	1.70	
Tilt Wing	120	I N	40	N 8
		$\bar{t}$	80.18	$\bar{t}$ 96.50
		σ_t	40.36	σ_t 31.39
		$\bar{x}$	6.23	$\bar{x}$ 6.62
		σ_x	1.22	σ_x 1.00
		II N	26	N 6
		$\bar{t}$	79.38	$\bar{t}$ 100.33
		σ_t	33.21	σ_t 23.73

APPENDIX B

Aircraft Type	Sound Duration Sec.	Level		Response	Changed Response	
			$\bar{x}$	2.54	$\bar{x}$	2.67
			σ_x	2.48	σ_x	2.71
Tilt Wing	240	I	N	41	N	21
			$\bar{t}$	108.29	$\bar{t}$	189.62
			σ_t	86.65	σ_t	48.45
			$\bar{x}$	4.71	$\bar{x}$	5.42
			σ_x	1.63	σ_x	2.16
		II	N	29	N	13
			$\bar{t}$	85.03	$\bar{t}$	195.38
			σ_t	67.74	σ_t	37.93
			$\bar{x}$	2.48	$\bar{x}$	1.30
			σ_x	1.61	σ_x	1.16

APPENDIX B

TABLE III

RESULTS OF PAIRED COMPARISON TEST FOR ADDED NOISE

COMPARISONS AIRCRAFT - LEVEL ADDED NOISE		PERCENT SUBJECTS WHO JUDGED SOUND WITH BACKGROUND		
AIRCRAFT - LEVEL	BACKGROUND	MORE ANNOYING	EQUAL	LESS ANNOYING
Jet - I Turbofan TF - I Tilt Wing - TW - I Helicopter - HEL - I	City Traffic	14% 41% 27% 46%	59% 50% 68% 46%	27% 9% 5% 8%
LEVEL I	Combined Average	32%	56%	12%
JET - I TF - I TW - I HEL - I	Highway Traffic	23% 32% 73% 50%	54% 50% 27% 36%	23% 18% - 14%
LEVEL I	Combined Average	45%	42%	14%
JET - II TF - II TW - II HEL - II	City Traffic	27% 41% 23% 50%	50% 32% 59% 41%	23% 27% 18% 9%
LEVEL II	Combined Average	35%	46%	19%
JET - II TF - II TW - II HEL - II	Highway Traffic	46% 41% 50% 68%	41% 54% 46% 27%	14% 5% 4% 5%
LEVEL II	Combined Average	51%	42%	7%

APPENDIX C

NOISE POLLUTION CALCULATIONS

This Appendix contains the Noise Pollution Level calculations for:

- H_1 - Helicopter Level 1
- H_2 - Helicopter Level 2
- T_1 - Turbofan Level 1
- T_2 - Turbofan Level 2
- J - Jet Reference
- V - Acoustical Energy

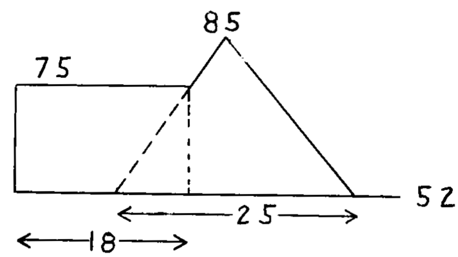
The Noise Pollution L_{NP} is found using tone-corrected Perceived Noise Level (PNL_T) measured in PNdB.

APPENDIX C

NOISE POLLUTION CALCULATIONS

I. Calculate L_{NP} for each aircraft

H_1

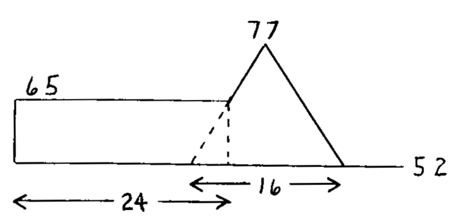


$$V_P = \left[(2.56)(85-52)\right]^2 \left[\frac{25}{3(3600)}\right] = 16.5$$

$$V_S = \left[(2.56)(75-52)\right]^2 \left[\frac{18}{3600}\right] = 17.3$$

$$V_{H_1} = V_P + V_S = 33.8$$

H_2



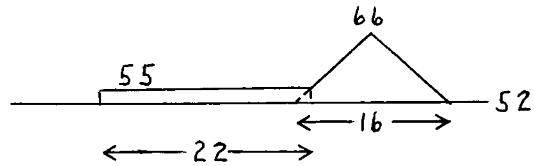
$$V_P = \left[(2.56)(77-52)\right]^2 \left[\frac{16}{3(3600)}\right] = 6.1$$

$$V_S = \left[(2.56)(65-52)\right]^2 \left[\frac{24}{3600}\right] = 7.4$$

$$V_{H_2} = V_P + V_S = 13.5$$

APPENDIX C

H_3

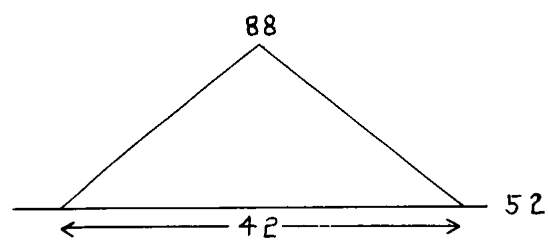


$$V_p = [(2.56)(66-52)]^2 \left[\frac{16}{3(3600)}\right] = 1.9$$

$$V_s = [(2.56)(55-52)]^2 \left[\frac{22}{3600}\right] = 0.4$$

$$V_{H_3} = V_p + V_s = 2.3$$

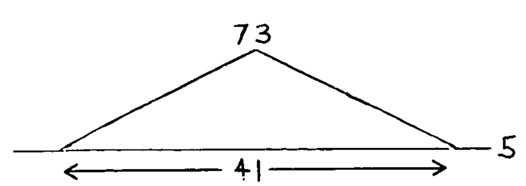
T_1



$$V_p = [(2.56)(88-52)]^2 \left[\frac{42}{3(3600)}\right] = 33.0$$

$$V_{T_1} = V_p = 33.0$$

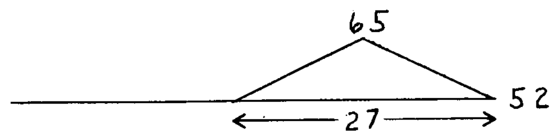
T_2



$$V_p = [(2.56)(73-52)]^2 \left[\frac{41}{3(3600)}\right] = 11.0$$

$$V_{T_2} = V_p = 11.0$$

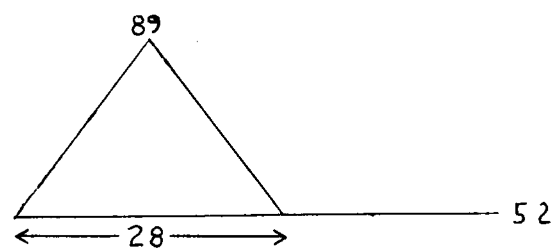
T_3



$$V_P = [(2.56)(65 - 52)]^2 \left[\frac{27}{3(3600)}\right] = 2.8$$

$$V_{T_3} = V_P = 2.8$$

J



$$V_P = [(2.56)(89 - 52)]^2 \left[\frac{28}{3(3600)}\right] = 23.3$$

$$V_J = V_P = 23.3$$

II. Combine aircraft into test sessions

$$V_H = V_{H_1} + V_{H_2} + V_{H_3} = 33.8 + 13.5 + 2.3 = 49.6$$

$$V_T = V_{T_1} + V_{T_2} + V_{T_3} = 33.0 + 11.0 + 2.8 = 46.8$$

$$\sum (V_H + V_T) = 49.6 + 46.8 = 96.4$$

$$V_J = 23.3$$

APPENDIX C

N = 6 Flights / Hr

$$\sqrt{VN} = \sqrt{\sum (V_H + V_T) + 2 V_J}$$

$$= \sqrt{96.4 + 2(23.3)}$$

$$= 12.0$$

N = 12 Flights / Hr

$$\sqrt{VN} = \sqrt{2\sum (V_H + V_T) + 2 V_J}$$

$$= \sqrt{2(96.4) + 2(23.3)}$$

$$= 15.5$$

N = 24 Flights / Hr

$$\sqrt{VN} = \sqrt{4\sum (V_H + V_T) + 2 V_J}$$

$$= \sqrt{4(96.4) + 2(23.3)}$$

$$= 20.8$$

N = 48 Flights / Hr

$$\sqrt{VN} = \sqrt{8\sum (V_H + V_T) + 2 V_J}$$

$$= \sqrt{8(96.4) + 2(23.3)}$$

$$= 28.6$$

APPENDIX D

PAIRED COMPARISONS SEQUENCE SURVEY

This Appendix contains instructions to the test subjects for the Paired Comparisons' Sequence. The middle sound (B) was the test sound and the comparison sounds (A) are identical.

APPENDIX D

PAIRED COMPARISONS SEQUENCE - NASA III
ANSWER SHEET

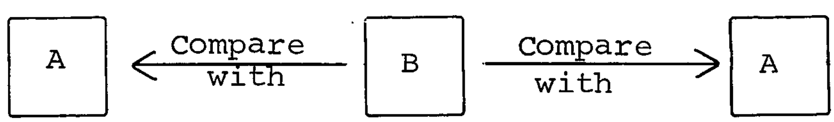
Test Ident. No. ______ Subject Name ____________________

I. STIMULUS SOUND

For this test you will hear three (3) sounds presented one after another. The first and last sounds are comparison sounds (A) and are identical. The second, or middle sound, is the test sound (B) which is different from the comparison sounds (A). Your responses for part II of this form are based on comparing the test sound (B) with the comparison sounds (A). Your response for part III is based on the test sound (B) only.

In diagram form the stimulus sounds will appear like this:

Comparison sound



II. RESPONSE (degree of annoyance)

Please place a check mark anywhere along the following continuum to indicate your judgment about the test sound (B) as compared to the comparison sounds (A):

Less* Annoying | Equally* Annoying | More* Annoying

* (Verbal instructions)

III. DESCRIPTION (of test sound 'B') -

Please underline any of the following words which help to describe the test sound (B):

piercing booming banging blaring roaring whining

screaming rumbling thundering resounding jarring

shrill powerful sharp soft resonant loud distant

(see next page)

harsh coarse muted hushed smothered muffled acute

ominous

Comments: ____

____

Please underline any of the following words which help to describe <u>your feeling</u> about the <u>test sound</u> (B):

troubled startled disturbed irritated relieved

oppressed distress alarm annoyed refreshed harassed

mortified bothered tormented happy calm uneasy

pleasant neutral anxious discomfort resentful despair

serene

Comments: ____

____

APPENDIX E

HACKMAN-DAVIS ANNOYANCE SURVEY

This Appendix contains 30 noise statements and 80 non-noise statements in order to determine a general annoyance factor for each test subject. In this survey, there were 28 test subjects and their mean rating is given.

APPENDIX E

HACKMAN-DAVIS ANNOYANCE SURVEY

NAME ______________________________ DATE ________________

This survey is designed to determine the amount of annoyance a variety of situations may produce for you. To record your reaction on each of the situations, please use the following numbers:

Range of responses

7,8, or 9 - -Extremely annoying(with 9 being most annoying)

4,5, or 6 - -Moderately annoying

1,2, or 3 - -Slightly annoying (with 1 being not annoying)

Thus, you are to record your degree of annoyance by writing a number (1 to 9) after each situation.

Examples:

1. Roaches in the sugar __7__
   If you consider this situation "extremely annoying", you would write "7", "8", or "9" in the bland space, depending upon your degree of annoyance. In this example, the person found the situation "extremely annoying" but not "8" or "9" level of annoyance.

2. To hear a person snoring __1__
   If you consider this situation "slightly or not annoying", you would write "1", "2", or "3" in the blank space, depending upon your degree of annoyance. In this example, the person found the situation "not annoying" at all.

Please record your degree of annoyance by writing a number (1 to 9) after each of the following situations. Do not spend too much time on any situation as your first reaction is most important.

1. To be pushed in a crowd 4.86
2. Public buildings not kept clean 4.54
3. To hear the back door continually banging shut 4.36
4. To follow a smelly bus in a car 6.25
5. Standing in a long line at the grocery store 5.67
6. Too many commercials during a movie on television 4.61
7. To hear a person cracking his chewing gum 4.30
8. Flies in the kitchen 5.18
9. To hear automobile horns blowing continually 6.04

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10. A passenger in the car telling me how to drive 4.68
11. People who gossip about others 4.68
12. To hear mosquitoes in the room 6.04
13. People smoking in a confined place 4.57
14. People satisfied with the status quo 4.50
15. To hear several lawn mowers running in the neighborhood 2.61
16. A person who throws trash from the car window 6.29
17. To be in the middle of a traffic jam 6.21
18. People who refuse to listen to my opinions 4.82
19. Trash in the streets 5.64
20. To hear the alarm clock ring loudly in the morning 4.00
21. A persistent salesman at my door 5.71
22. To hear a low-flying jet overhead 3.07
23. A person who acts as though he knows everything 5.46
24. To observe a person's nose running 5.61
25. To work in the yard 2.46
26. To hear screaming kids playing in the yard 2.57
27. To observe an untidy room 3.43
28. Locking the keys in the car 6.36
29. Polluted streams 6.79
30. Construction on major roads during rush hour 6.43
31. To hear chalk squeaking on a blackboard 5.07
32. A dripping ice cream cone 2.71
33. To hear dogs barking when I am trying to sleep 4.86
34. Ready to take a bath and find no hot water 5.32
35. A person who sneezes without covering his mouth 5.50
36. Running out of ice at a party 4.43
37. To go to a sale and find the sale items are sold out 4.64
38. Young people taking drugs 6.93
39. To hear water dripping from a faucet 5.14
40. To observe an intoxicated person 3.89
41. Dirty ash trays in several rooms 4.14
42. To hear a car pass by with a hole in the muffler 3.75
43. Being unable to find a pen that writes 3.78
44. Discovering the television schedule was not correct 3.18
45. To hear a neighbor's television playing loudly 3.71
46. The smell of industrial smoke in the air 6.04
47. People who just chatter 4.67
48. To hear a speaker talk very loudly 4.25
49. Men who do not stand when a woman enters the room 2.36
50. To hear interference on the radio 4.89
51. Warm water from the water fountain 4.11
52. Ants on the table during a picnic 4.35
53. Pollution in the air 6.36
54. To hear cats fighting when I am reading 4.42
55. Dirty clothes on the floor 4.42
56. A person who leaves food on his plate regularly 3.00
57. To hear the running of a vacuum cleaner 2.79
58. To find hair in my food 6.67
59. To hear the prolonged ringing of a telephone 5.71
60. A person monopolizing the conversation 5.07
61. To see lipstick on a water glass 5.17
62. A person who continually wishes to borrow your things 4.82

63. Neighbors entertaining a large group late at night 2.50
64. To see a person with dirty finger nails 3.57
65. To invite people to your home and have them arrive early 2.91
66. A rude telephone operator 5.11
67. To hear a helicopter hovering over your house 5.29
68. Cruelty to animals 8.00
69. To hear the tapping of a pencil on a desk 4.17
70. A person who does not really pay attention when I speak 5.21
71. Stray dogs in the neighborhood 3.79
72. To hear the screeching of tires as cars continually start and stop quickly 5.39
73. A person with bad breath 6.17
74. Sensational headlines found in newspapers 3.25
75. To hear someone eat his soup noisely 4.46
76. Hair in the bathroom bowl 3.60
77. To see a man who needs a shave or haircut 2.36
78. To hear very loud music 4.32
79. To be laughed at 5.14
80. Getting up early in the morning 4.71
81. When I can't recall someone's name 4.79
82. To hear sirens during the night 3.71
83. A person with bad table manners 4.57
84. To find the toothpaste tube with the cap off 2.82
85. To just miss your bus 5.21
86. To hear the prolonged crying of someone else's baby 5.07
87. Being misquoted 5.89
88. Pornography in our magazines 3.50
89. To hear heavy traffic noises in the morning 4.90
90. To wait for a person who is late 5.36
91. Finding a page torn out of a book I am reading 5.79
92. Rude sales clerk in a department store 6.43
93. To hear loud thunder at night 3.43
94. To have a person jump ahead of you in a line rather than waiting his turn 7.29
95. Crowded rooms 3.64
96. To hear people talking in a library 3.61
97. Uncleanliness of a person 5.50
98. Political advertisements on television 3.00
99. Detours when on a trip 3.67
100. A broken zipper 4.85
101. To hear a jack hammer as a person repairs the street 5.00
102. A doctor being late for your scheduled appointment 4.75
103. The kind of films being shown at my local theaters 2.46
104. A tire going flat on the car 5.43
105. To forget an item at the grocery store 4.14
106. Not being served promptly in a restaurant 4.75
107. Failur to receive any compliment regarding your new clothes 2.68
108. To hear the volume go up on television during commercials 4.64
109. Careless drivers 6.79
110. Taking tests and surveys 3.68

APPENDIX F

HACKMAN-DAVIS OPINION QUESTIONNAIRE - PUBLIC REACTION TO AIRCRAFT SOUNDS

This Appendix is an opinion questionnaire regarding aircraft noise under various conditions. It was administered to seventeen male subjects and their mean rating is given.

APPENDIX F

HACKMAN-DAVIS
OPINION QUESTIONNAIRE
PUBLIC REACTION TO AIRCRAFT SOUNDS

INSTRUCTIONS: The purpose of this questionnaire is to obtain information on how people generally react to aircraft noise and other sounds. We are asking you as experienced observers to tell us how you think people, including yourself, generally feel about noise and how annoyed they are with it. Please use our rating scale (1-9) and record your judgments in the proper spaces. If you have no opinion about a particular type of noise, leave that item blank.

1. How annoyed are people when hearing loud aircraft sounds when the aircraft is:

RATING	CONDITIONS
7.71	on ground-testing engines
7.41	hovering overhead (helicopter)
5.71	approaching level flight
5.59	going away-level flight
5.19	flying crosswise
4.75	flying around in holding pattern
7.65	taking off
6.18	landing

Which of the above would annoy you the most? __________

2. How annoying are sounds made by each of the following aircraft?

RATING	CONDITIONS
6.12	Helicopters
7.47	Jets
5.29	Propeller driven
6.12	Turboprops

APPENDIX F

Which of the above is most annoying to you personally?

____

3. To what extent are people annoyed by the following sounds?

Rating	Description	Rating	Description	Rating	Description
8.5	piercing	6.52	thundering	3.18	muted
7.41	crashing	5.63	dissonant	4.35	rumbling
8.30	shrill	7.82	screeching	6.48	jarring
7.59	startling	6.59	clattering	6.12	abrupt
6.56	staccato	6.24	loud	5.06	intermittent
7.64	blaring	7.06	booming	6.77	roaring
6.50	intruding	7.06	harsh	6.64	sudden
6.06	scratching	8.12	shrieking	6.52	banging
4.29	echoing	7.63	penetrating	5.89	scraping
6.77	grinding	5.35	whistling	4.77	hissing
5.82	buzzing	5.06	stuttering	5.77	howling
5.65	ringing	6.48	screaming	6.48	yelling

4. How annoyed are people when the frequency of occurrence is:

RATING	FREQUENCY
2.40	less than once per hour
4.59	about six per hour
6.18	about twelve per hour
7.53	about twenty-four per hour
8.41	about forty-eight per hour
7.94	a series of loud sounds at irregular intervals over a long period of time

Which of the above would annoy you the most? ___________

5. How annoyed are people by loud aircraft sounds when they are engaged in the following activities?

RATING	ACTIVITY
5.53	working in office or shop
5.29	working at home
5.41	recreation at home outdoors
4.06	playing games indoors
6.35	watching TV
6.12	listening to radio
5.88	leisure reading
3.88	doing household chores
3.94	hobbies, handcrafts
6.29	talking on telephone
5.00	eating
4.56	sleeping
7.17	carrying on conversation
5.06	at outdoor athletic events

Which of the above would annoy you the most? ____________

6. In general, how annoyed are you at aircraft noise? ______

7. Under what conditions are you bothered the most by aircraft noise?

REFERENCES

1. Hinterkeuser, E.G. and Sternfeld, H. Jr., "Subjective Response to Synthesized Flight Noise Signatures of Several Types of V/STOL Aircraft", Boeing Vertol Company, NASA Contractor Report CR-1118, 1968.
2. Sternfeld, Harry Jr., Hinterkeuser, Ernest G., Hackman, Roy B., Davis, Jerry, "Acceptability of VTOL Aircraft Noise Determined by Absolute Subjective Testing, Boeing Vertol Company, NASA Contractor Report CR-2043, 1972.
3. Anonymous, "Definitions and Procedures for Computing the Perceived Noise Level of Aircraft Noise", Society of Automotive Engineers, Inc., Report 865A, August 15, 1969.
4. Anonymous, Aircraft Noise Evaluation Technical Report FAA-NO-68-34 Federal Aviation Administration, September, 1968.
5. Robinson, D.W., "A New Basis for Aircraft Noise Rating", National Physical Laboratory Aerodynamic Report AC 49, March 1971.
6. Lowson, M.V. and Ollerhead, J.B., "Studies of Helicopter Rotor Noise", U. S. AAMRDL Report TR68-60, January 19, 1969.
7. Fry, Bernard L., "Feasibility of V/STOL Concepts for Short Haul Transport Aircraft", Boeing Vertol Company, NAS 2-3142.
8. Sikorsky Aircraft, "Information Response of Sikorsky Aircraft", Volume I, Civil Aeronautics Board, Northeast Corridor VTOL Investigation (Docket 19078).

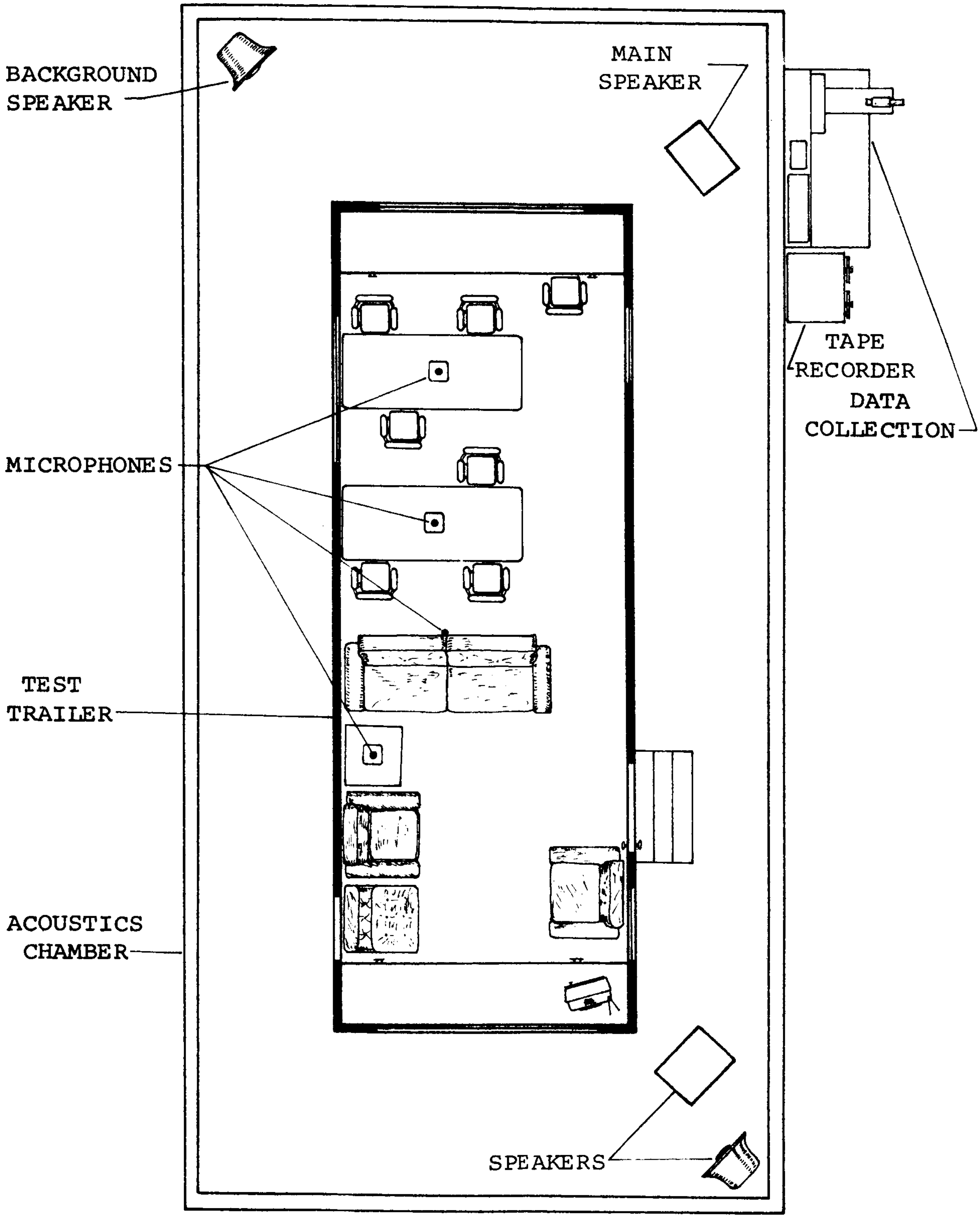


FIGURE 1. Test Environment - Plan View

WORK ENVIRONMENT

LEISURE ENVIRONMENT

FIGURE 2. Test Subjects in Work and Leisure Environment.

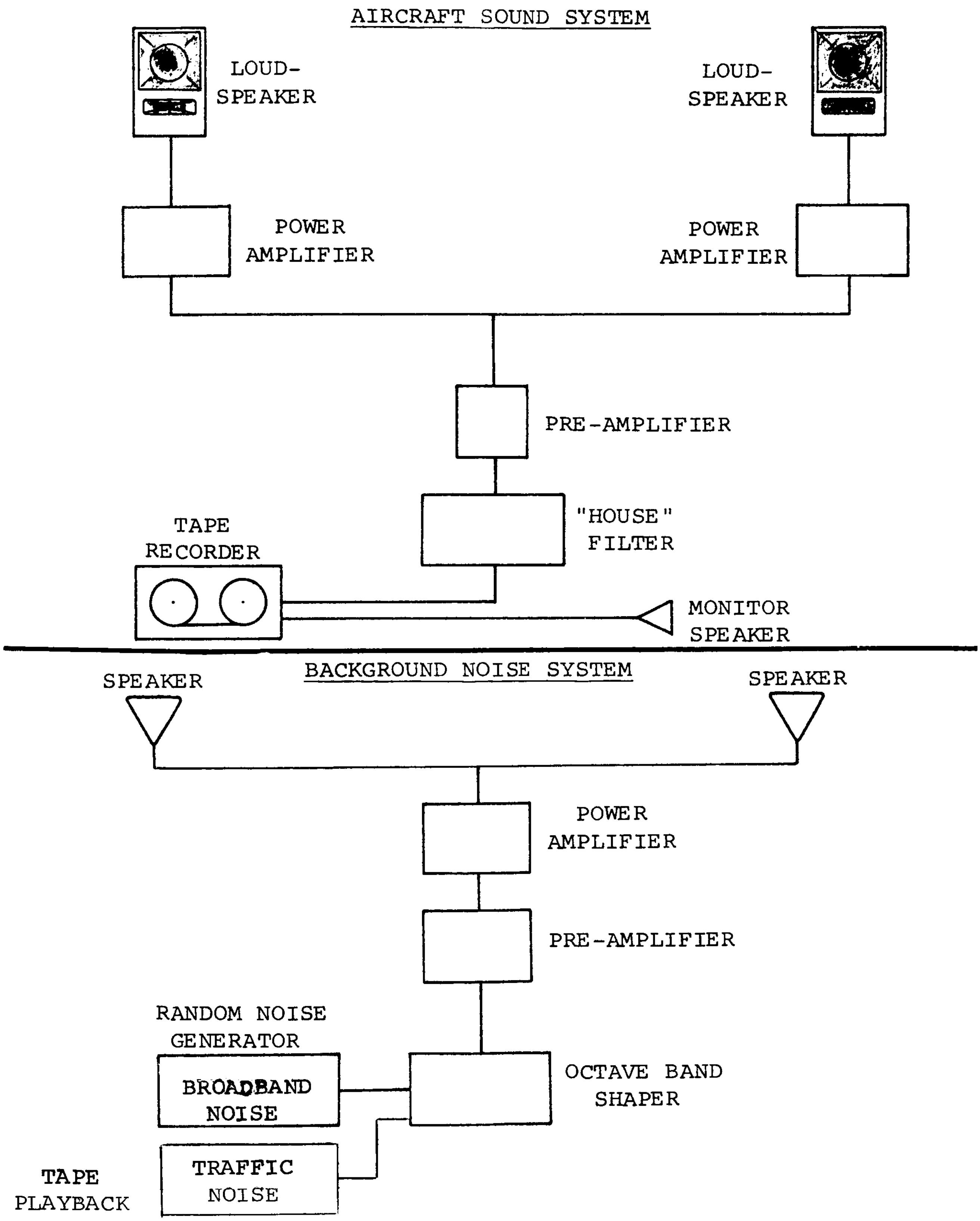


FIGURE 3. Acoustical System for Sound Generation

(FULL SIZE)

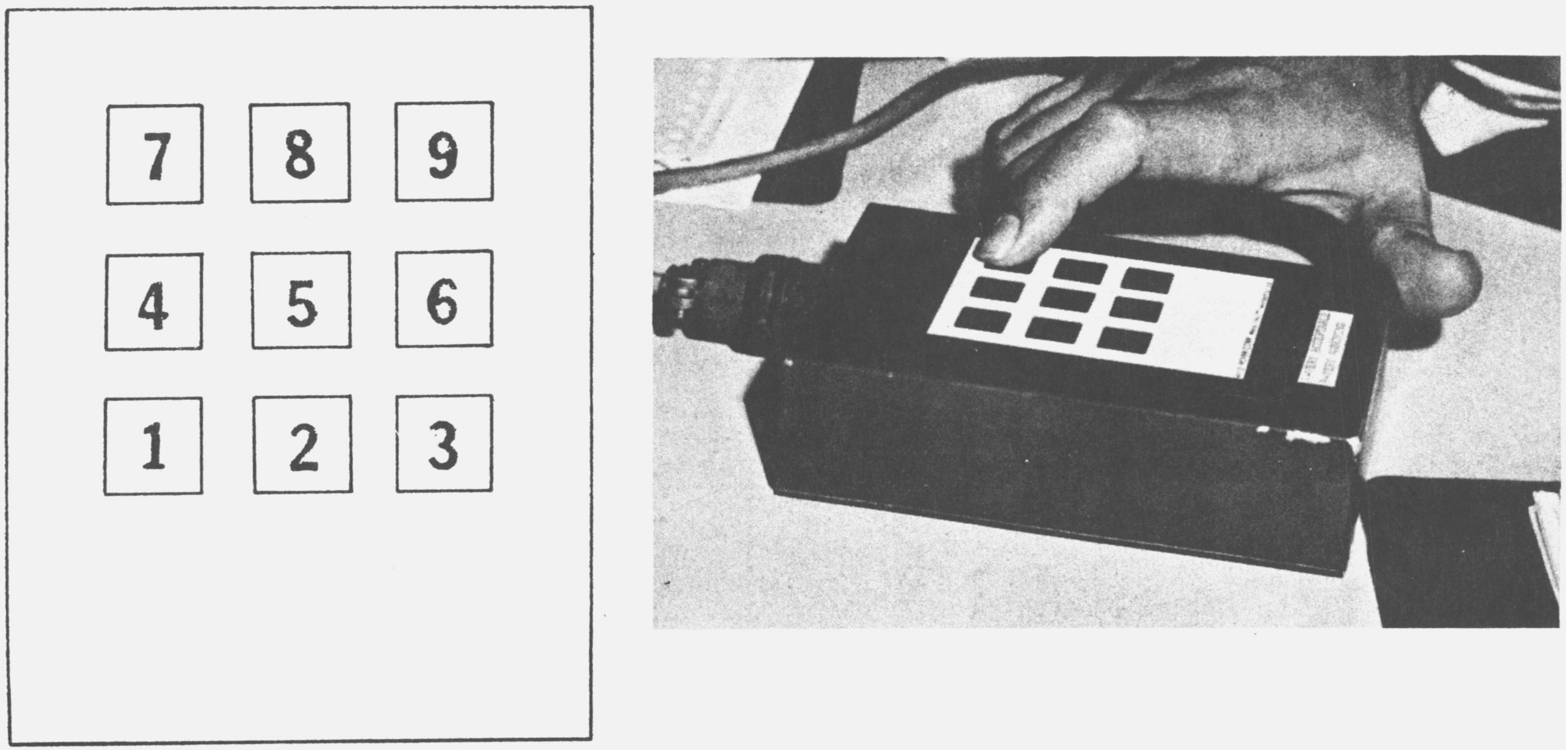
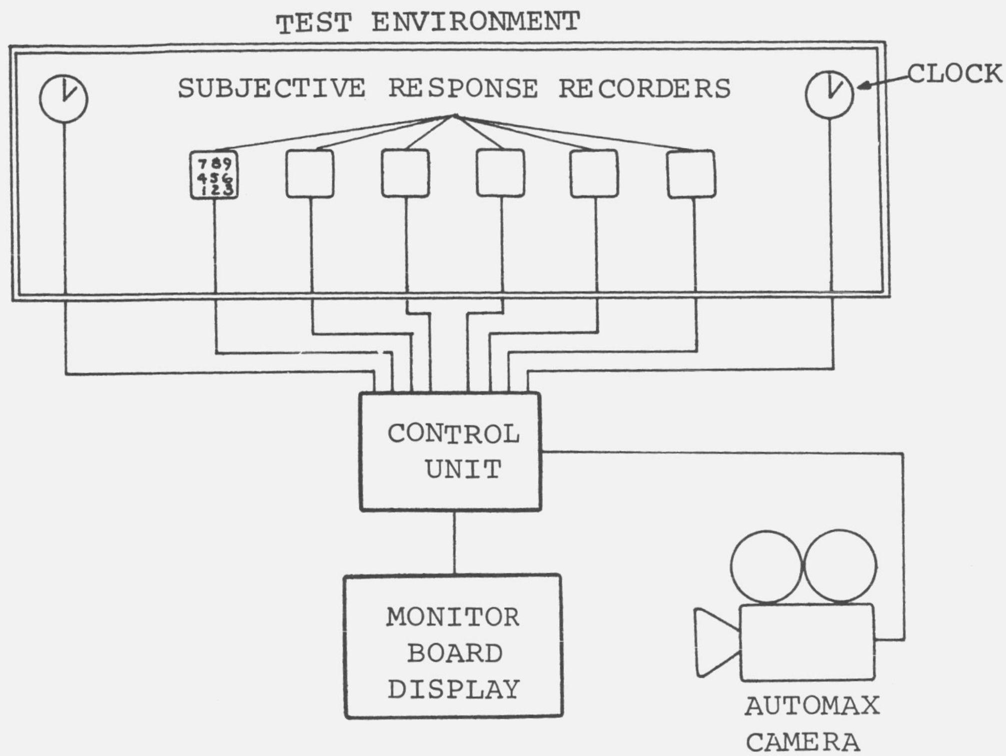


FIGURE 4. Subjective Response Recorder



SUBJECTIVE RESPONSE MONITOR BOARD DISPLAY

FIGURE 5. Subjective Response Recording System

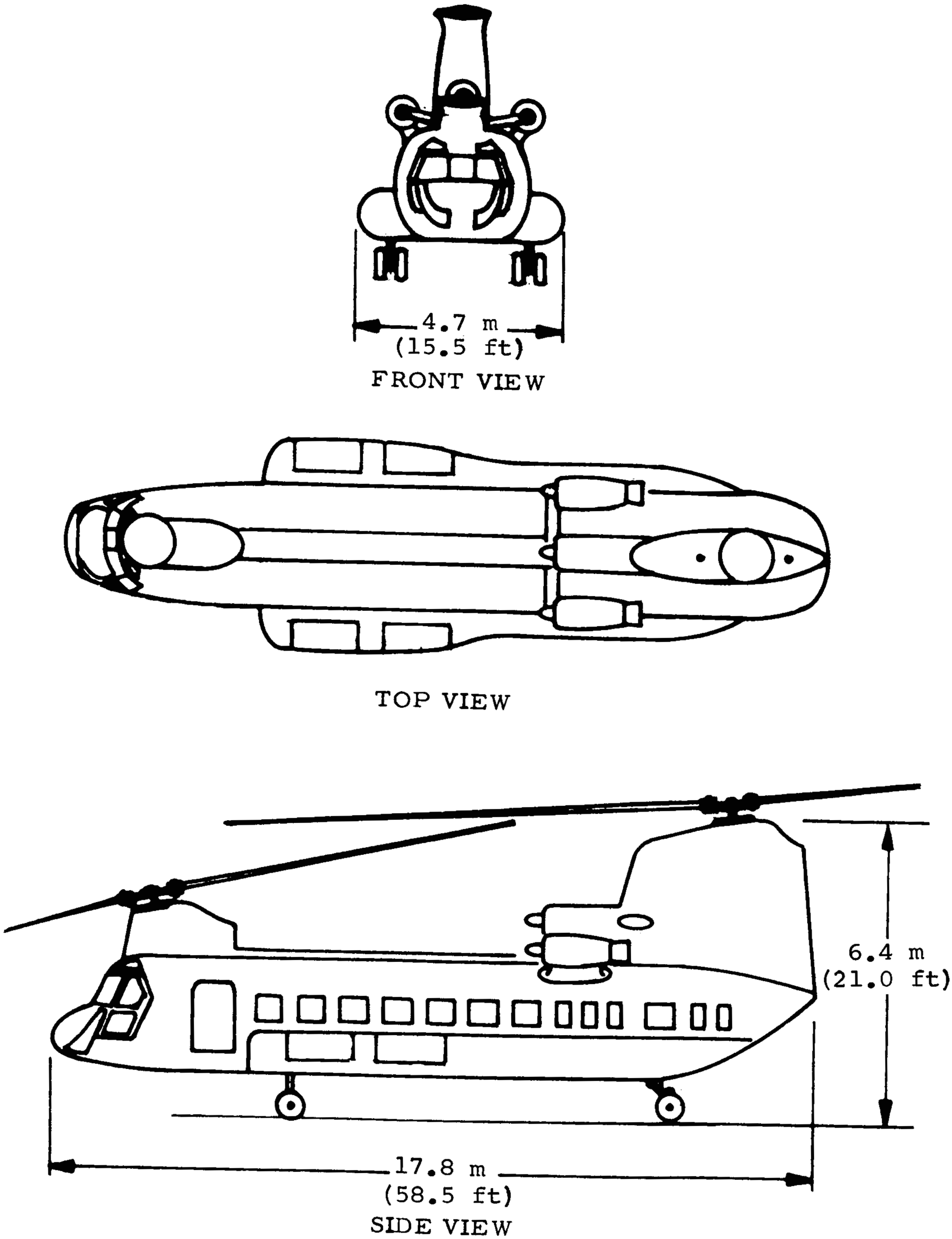


FIGURE 6. Tandem Rotor Configuration

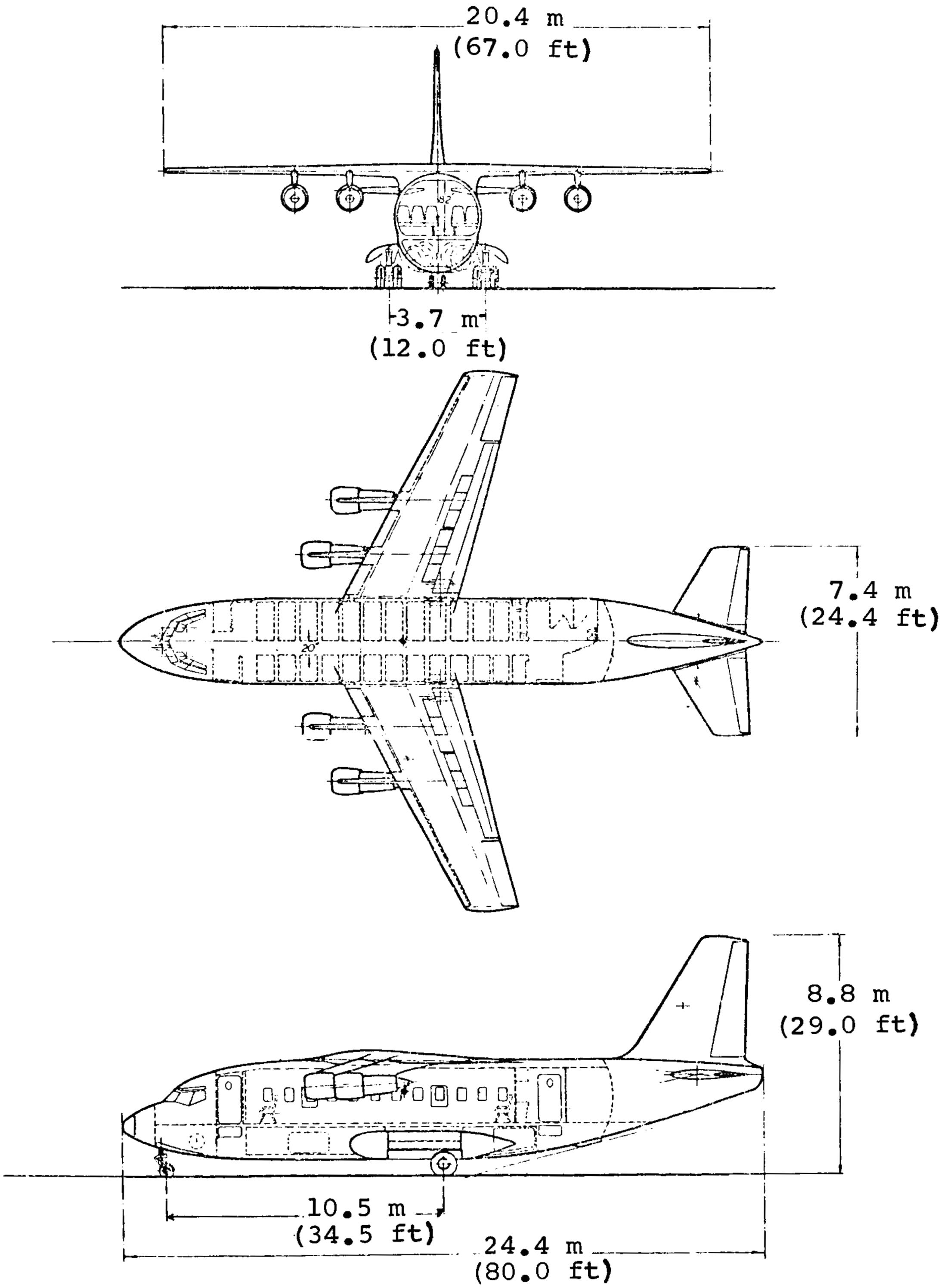


FIGURE 7. Turbofan STOL Configuration.

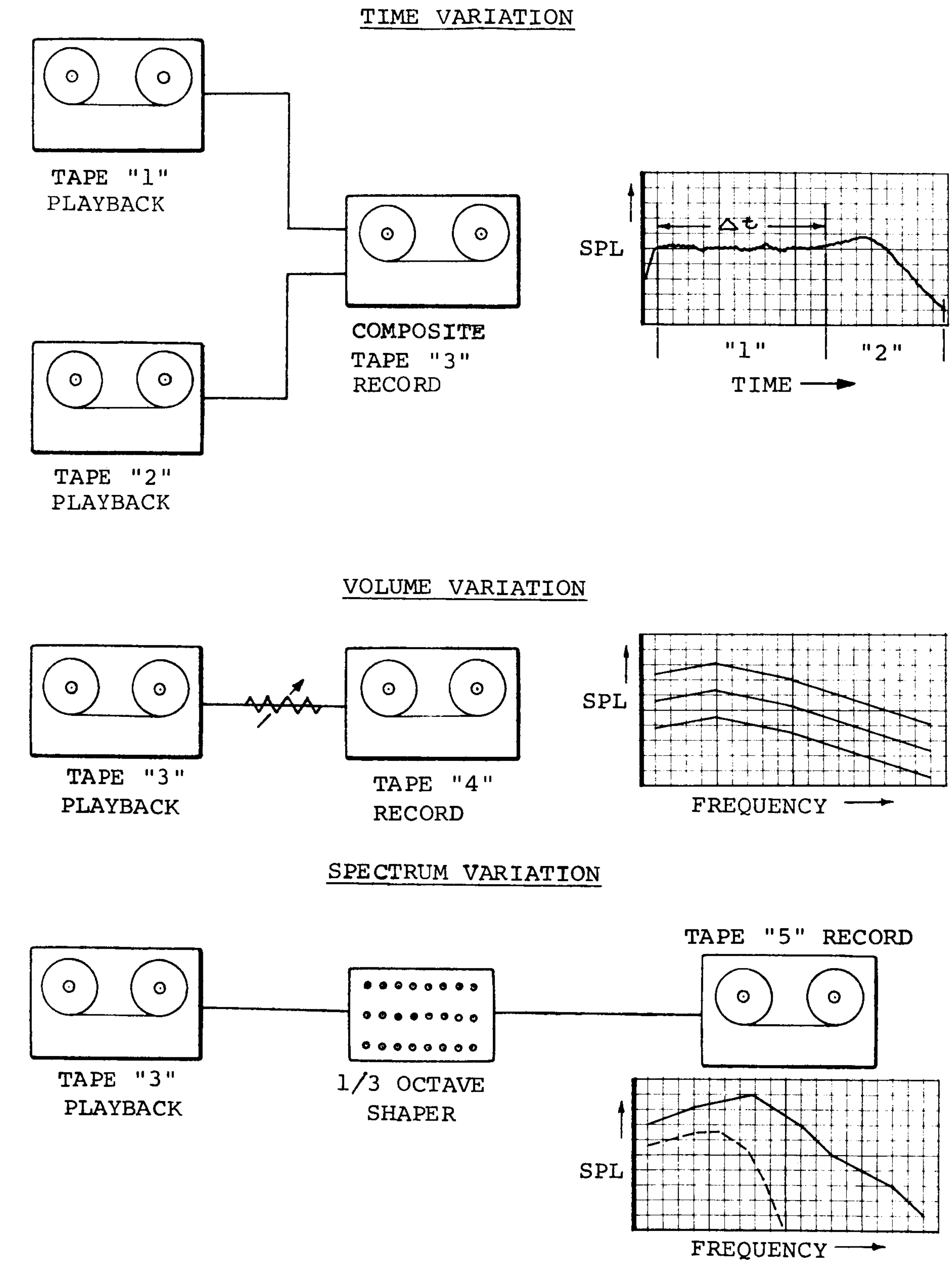


FIGURE 8. Methods of Tape Preparation.

SPL	LEVEL 1	LEVEL 2	LEVEL 3
dBC Hover dBC Peak	77.0 85.0	70.0 77.5	57.0 66.0
dBA Hover dBA Peak	60.0 71.0	52.0 63.1	41.0 51.1
PNdB Hover* PNdB Peak**	73.0 84.5	65.0 75.8	52.0 63.2
EPNL**	81.9	72.8	62.9
Time, Seconds			
t_1 t_2 t_3	4 25.5 38	4 29 37	2 28 36

* Mean

** From 1/3 octave every 1/2 second

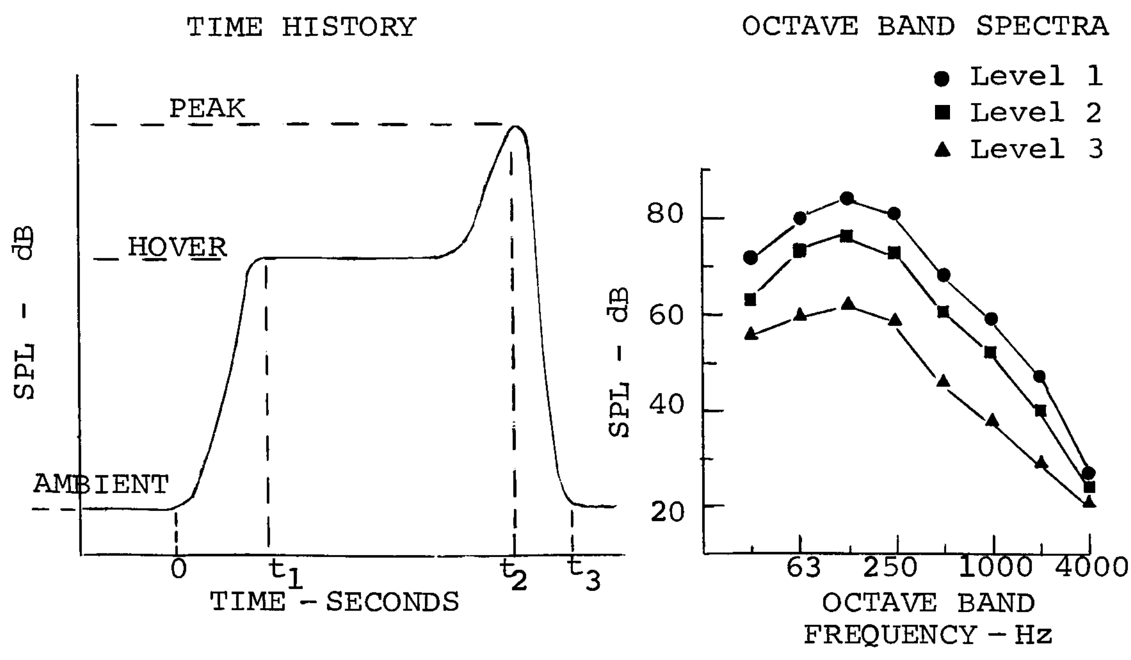
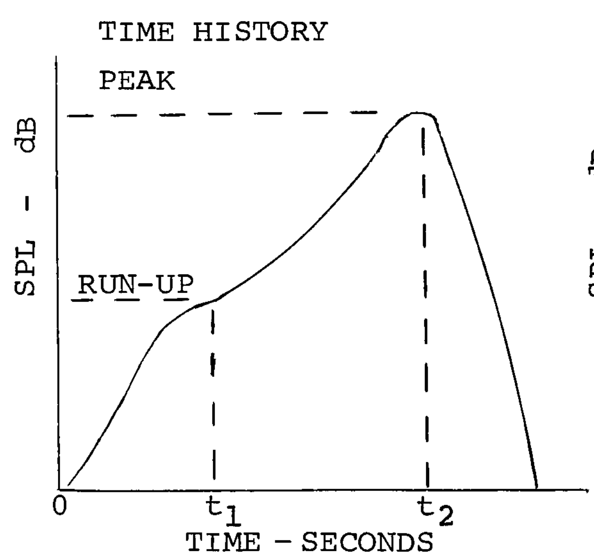


FIGURE 9. Acoustical Data Presented to Test Subjects - Helicopter

SPL	LEVEL 1	LEVEL 2	LEVEL 3
dBC Run-up dBC Peak	73.0 84.2	62.0 70.7	57.0 63.7
dBA Run-up dBA Peak	65.0 74.3	55.0 62.0	43.0 52.9
PNdB Run-up* PNdB Peak**	75.0 86.6	63.0 71.3	52.0 63.4
EPNL **	87.7	74.3	-
Time, Seconds			
t_1 t_2	10 24	6 24	8 26

* Mean
** From 1/3 octave every 1/2 second



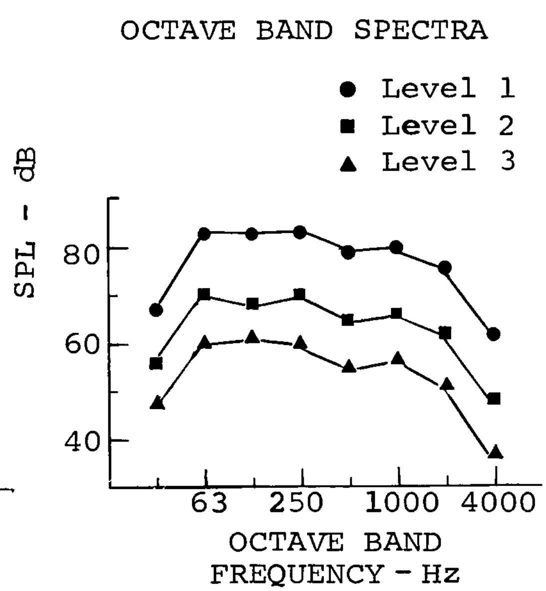


FIGURE 10. Acoustical Data Presented to Test Subjects - Turbofan STOL

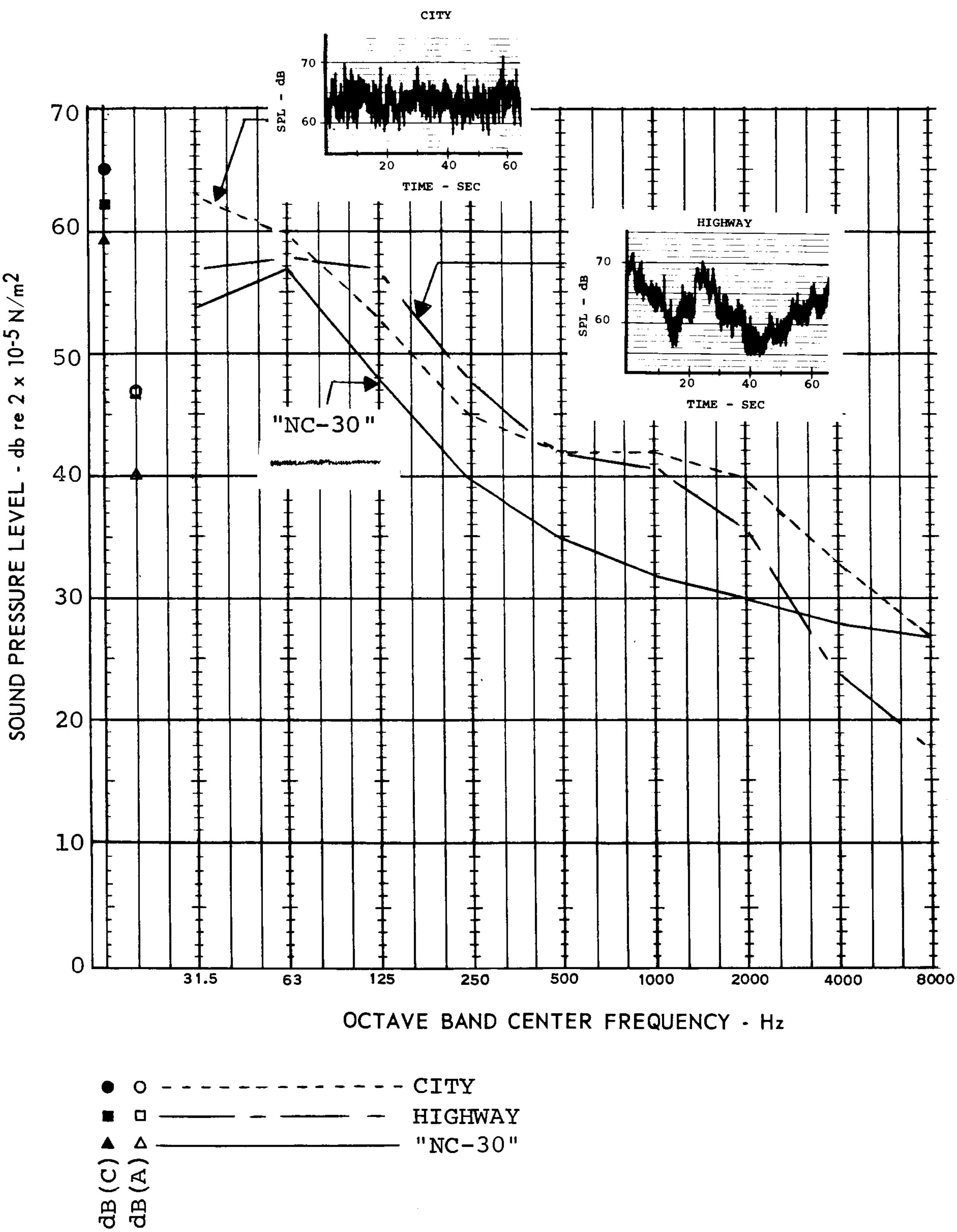


FIGURE 11. Acoustical Data Presented to Test Subjects - Ambient Noise

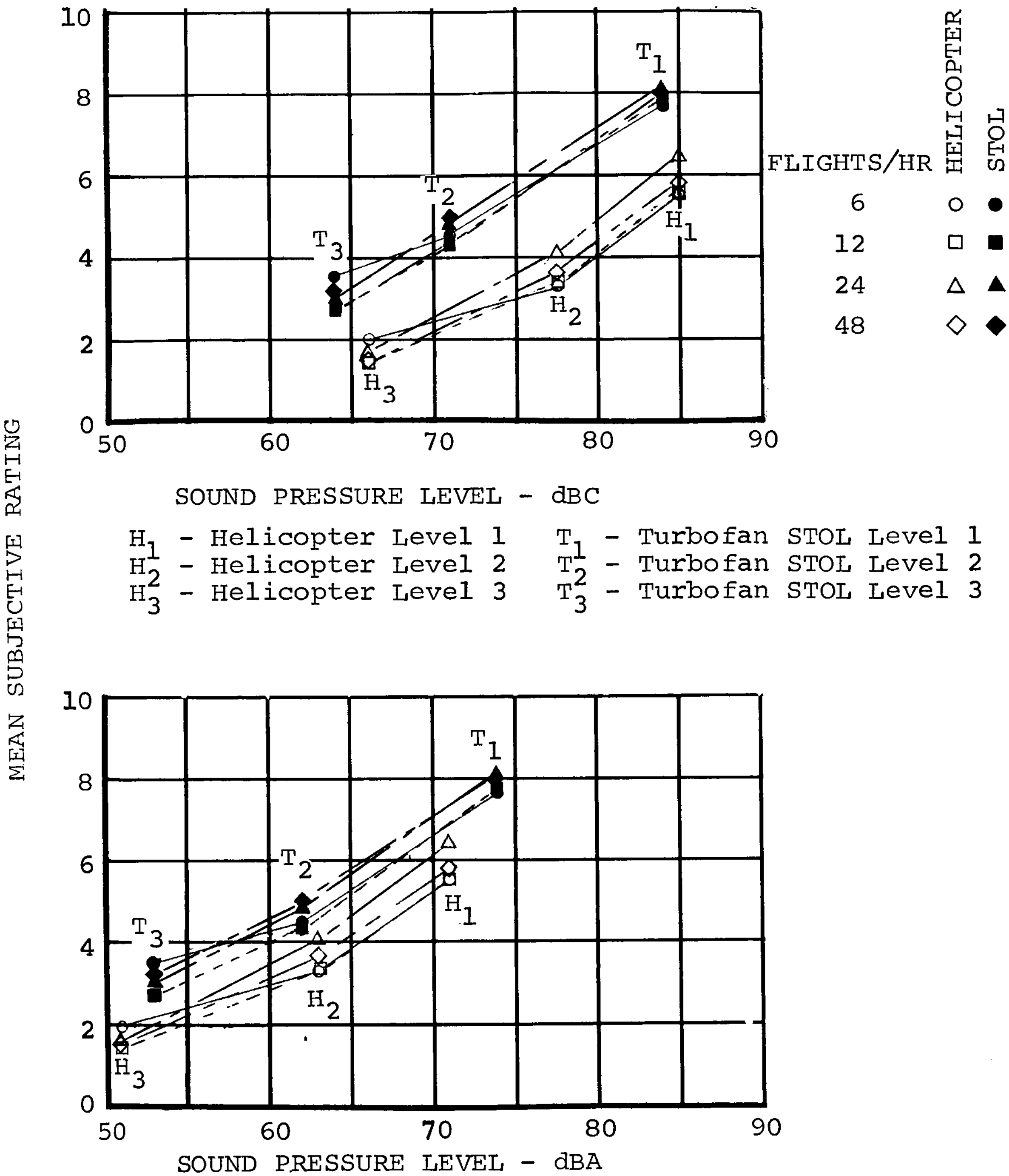


FIGURE 12. Correlation of Subjective Ratings with Sound Pressure Level

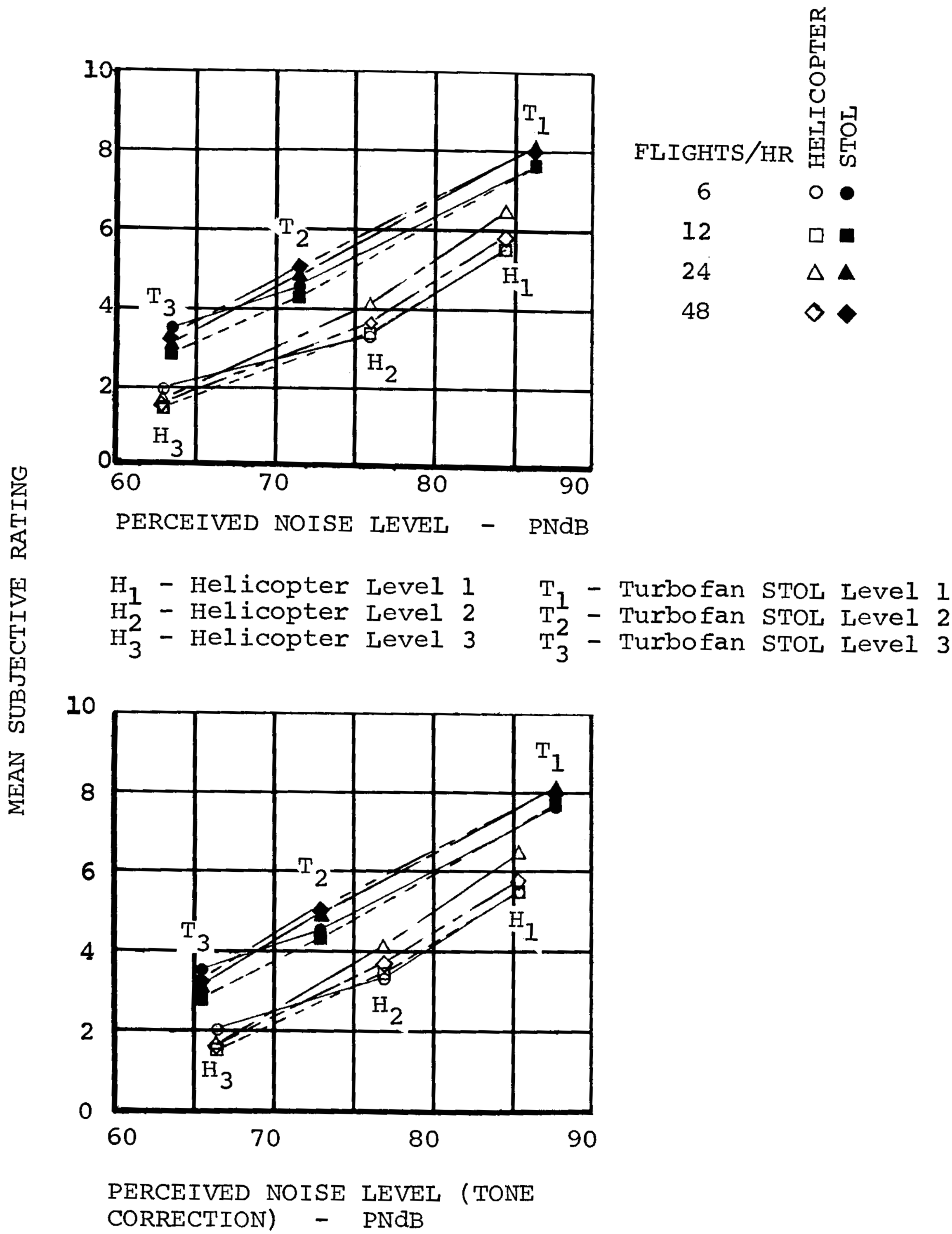


FIGURE 13. Correlation of Subjective Ratings with Perceived Noise Level

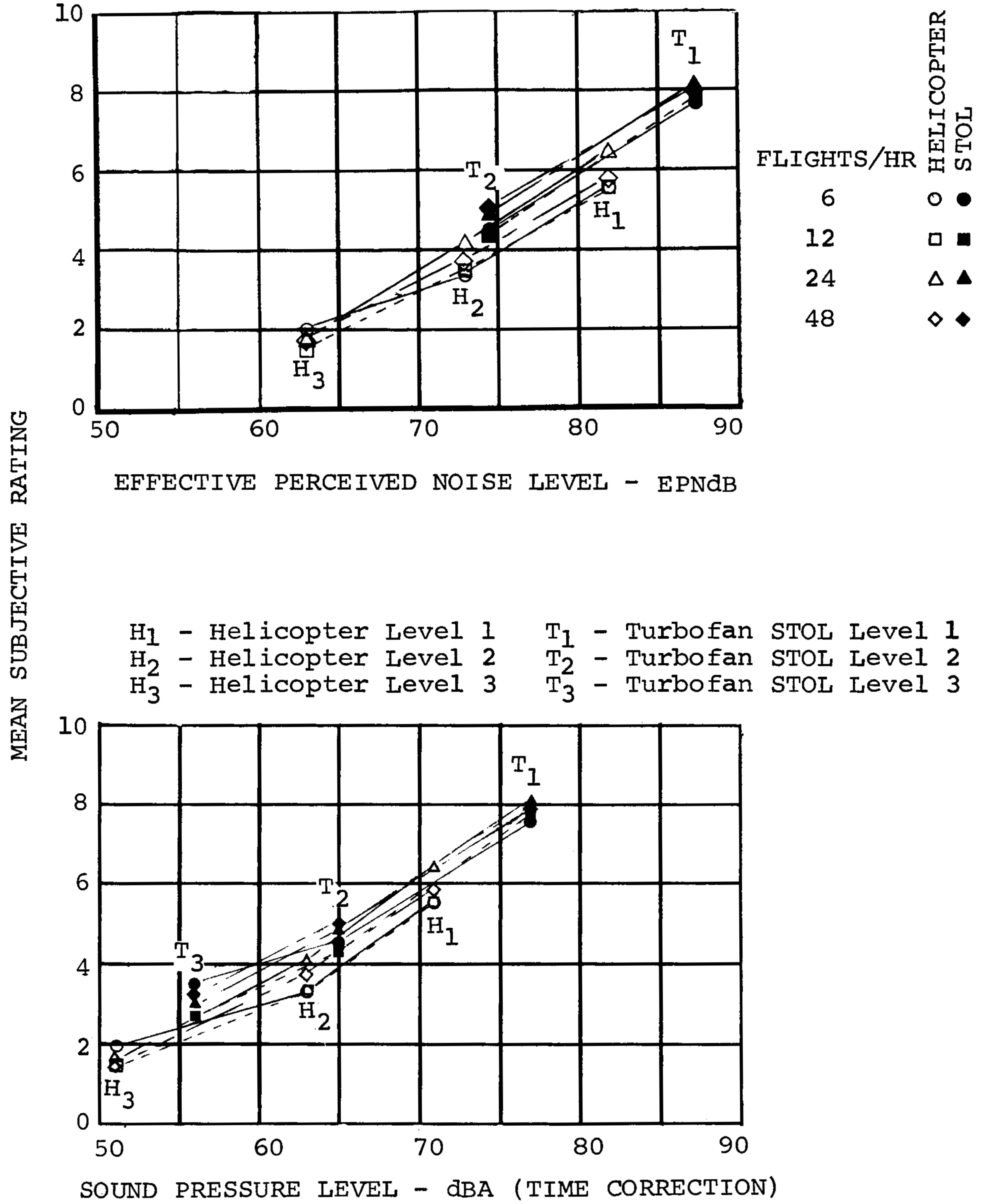


FIGURE 14. Correlation of Subjective Ratings with Effective Perceived Noise Level and Time Corrected dBA

Helicopter -30 Sec. Duration at 24 flights/hour (male only)

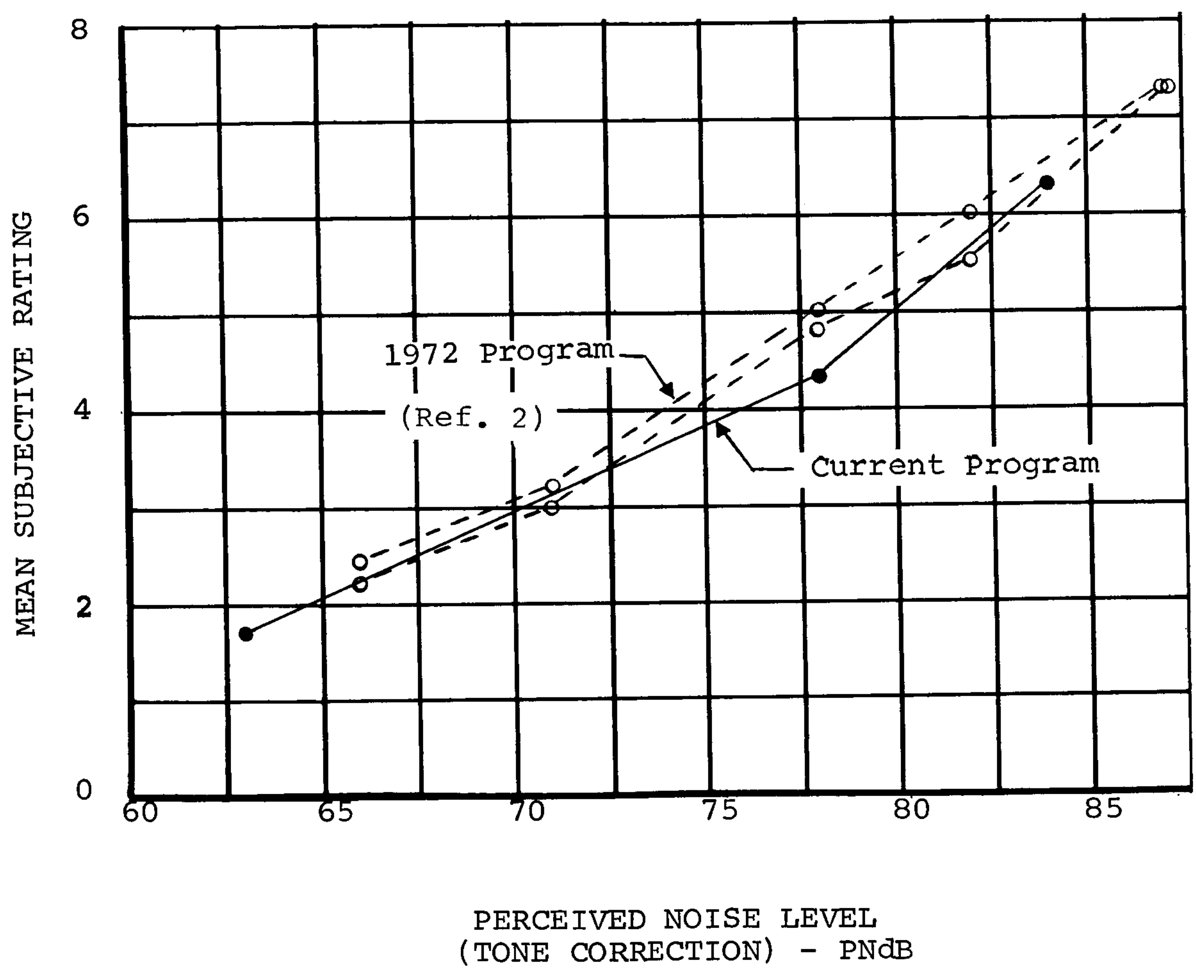


FIGURE 15. Comparison of Results of Ref. 2 and Current Programs

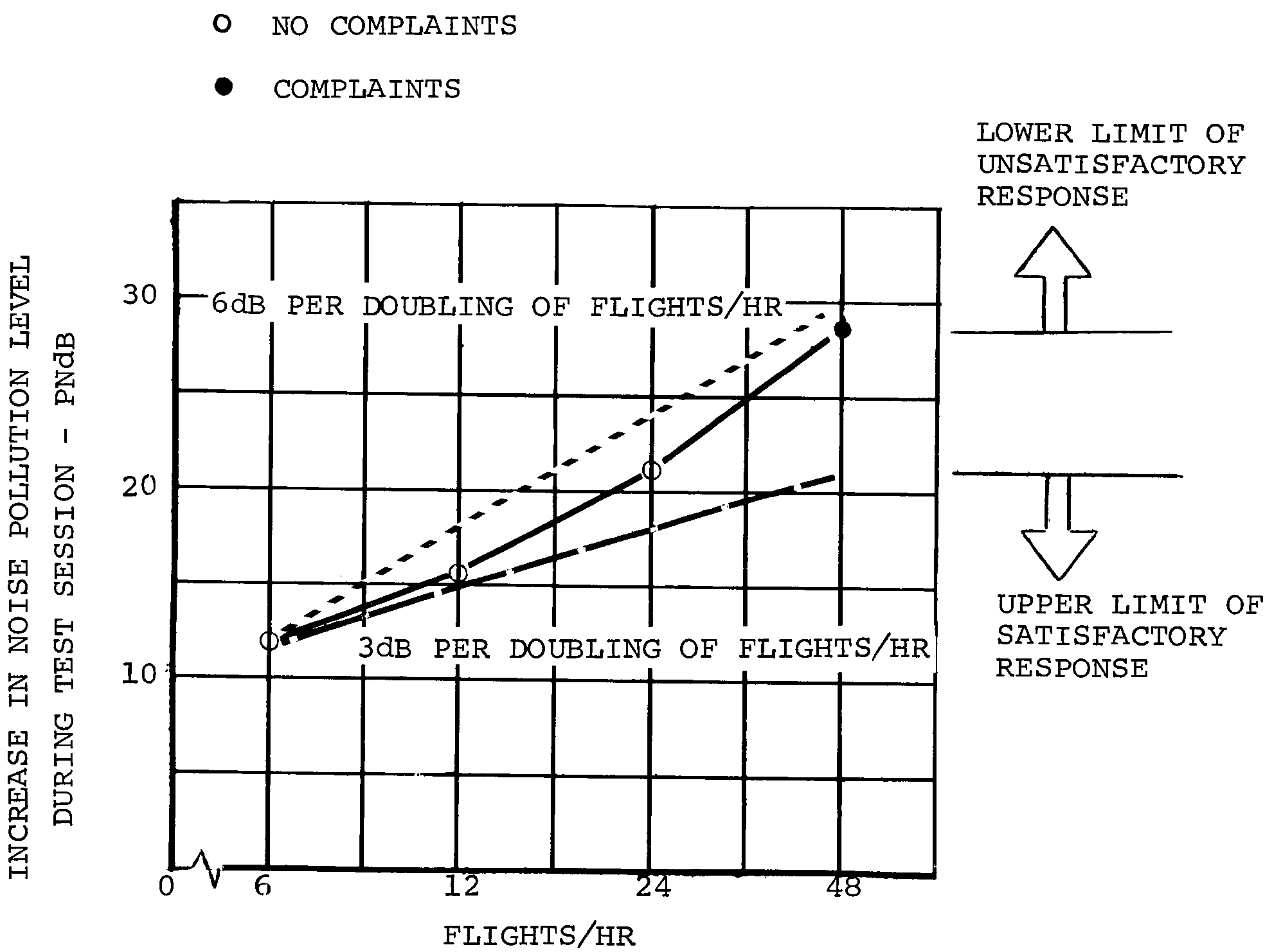
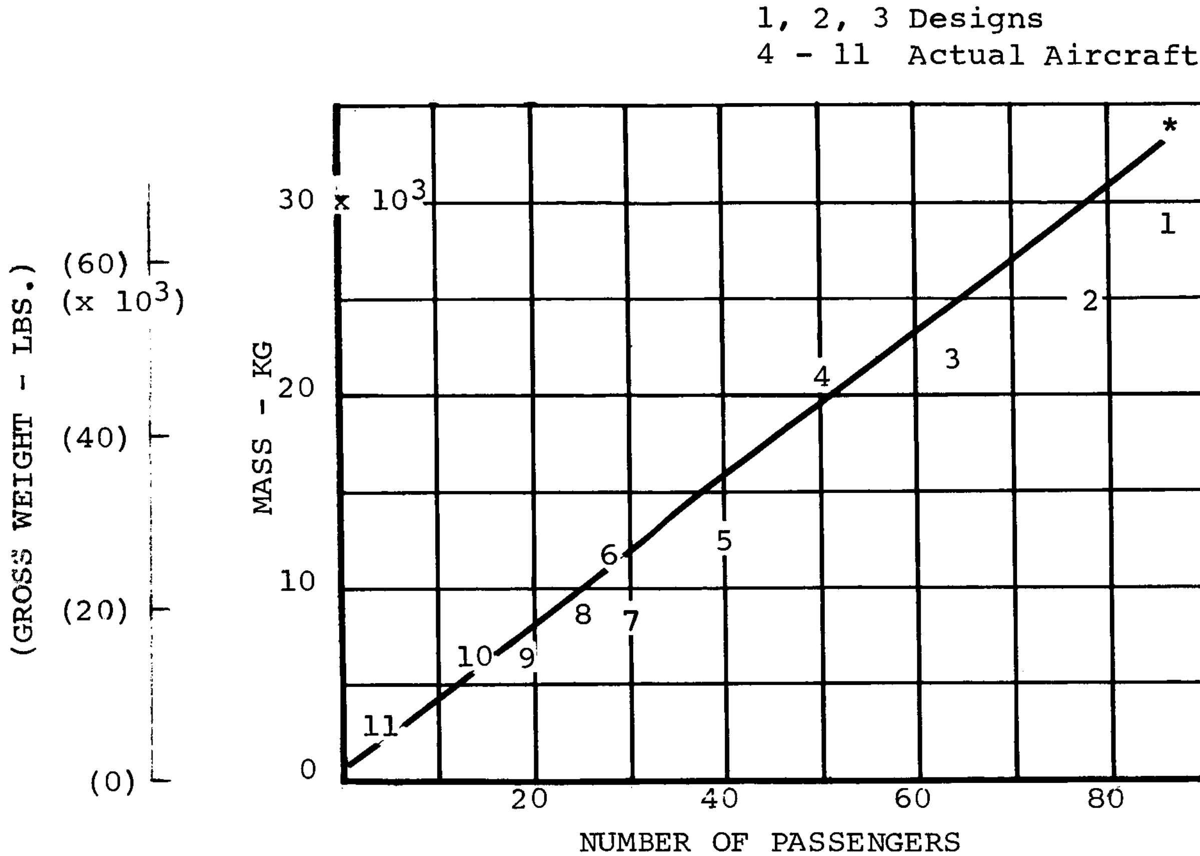


FIGURE 16. Noise Pollution Levels of Subjective Test Sessions - "NC-30" Background Level



(Data Ref. 7 & 8 and Boeing-Vertol Test Data)

1. S-65
2. 177
3. 167
4. 347
5. Frelon SA321-F
6. MI-8
7. S-61
8. 107-II
9. SNECMA-SA330F (Puma)
10. Bell 212
11. BO-105

(*) Least Squares Fit Through
Actual Aircraft (4-11) Only

FIGURE 17. Statistical Trend of Passenger Capacity vs. Mass - Helicopters

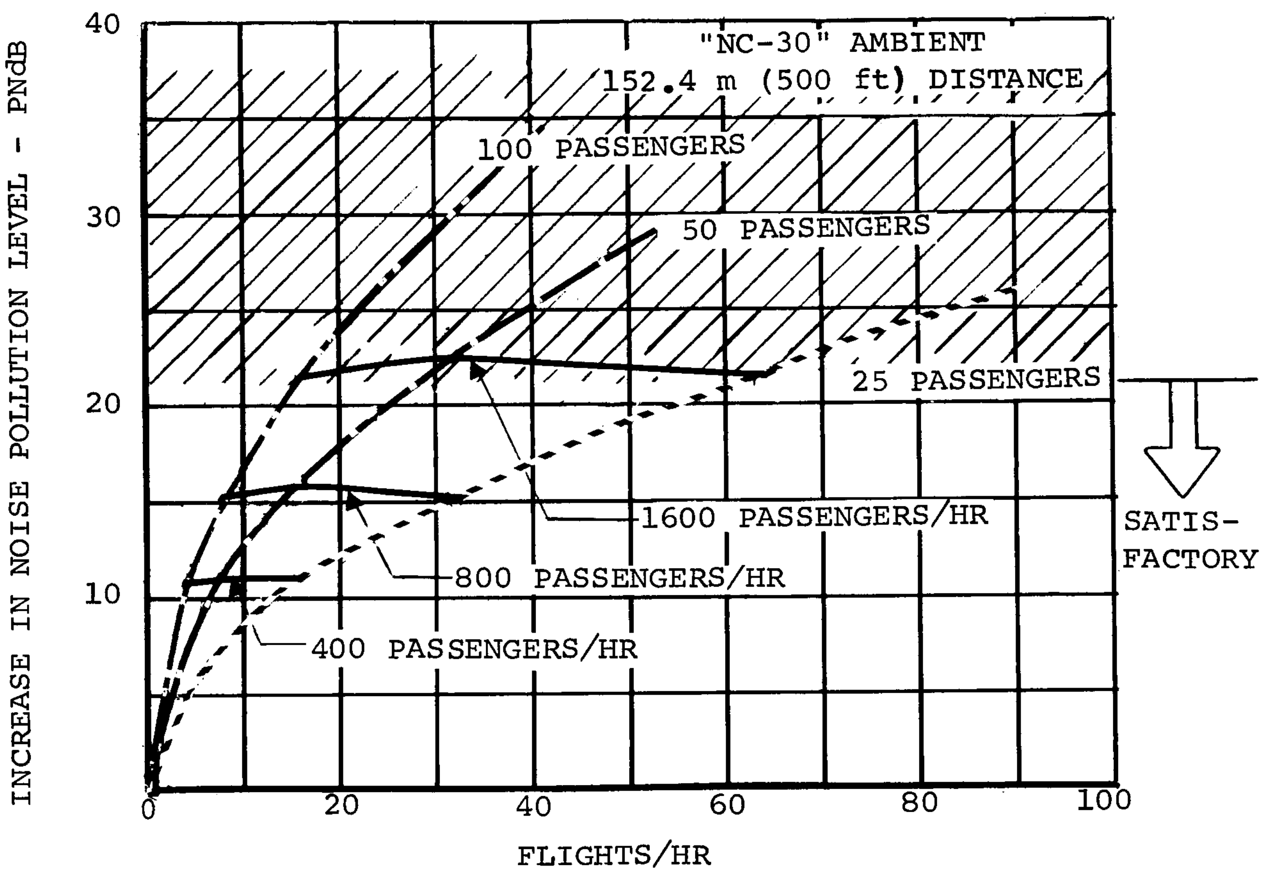


FIGURE 18. Results of Sample Helicopter Noise Tradeoff Study

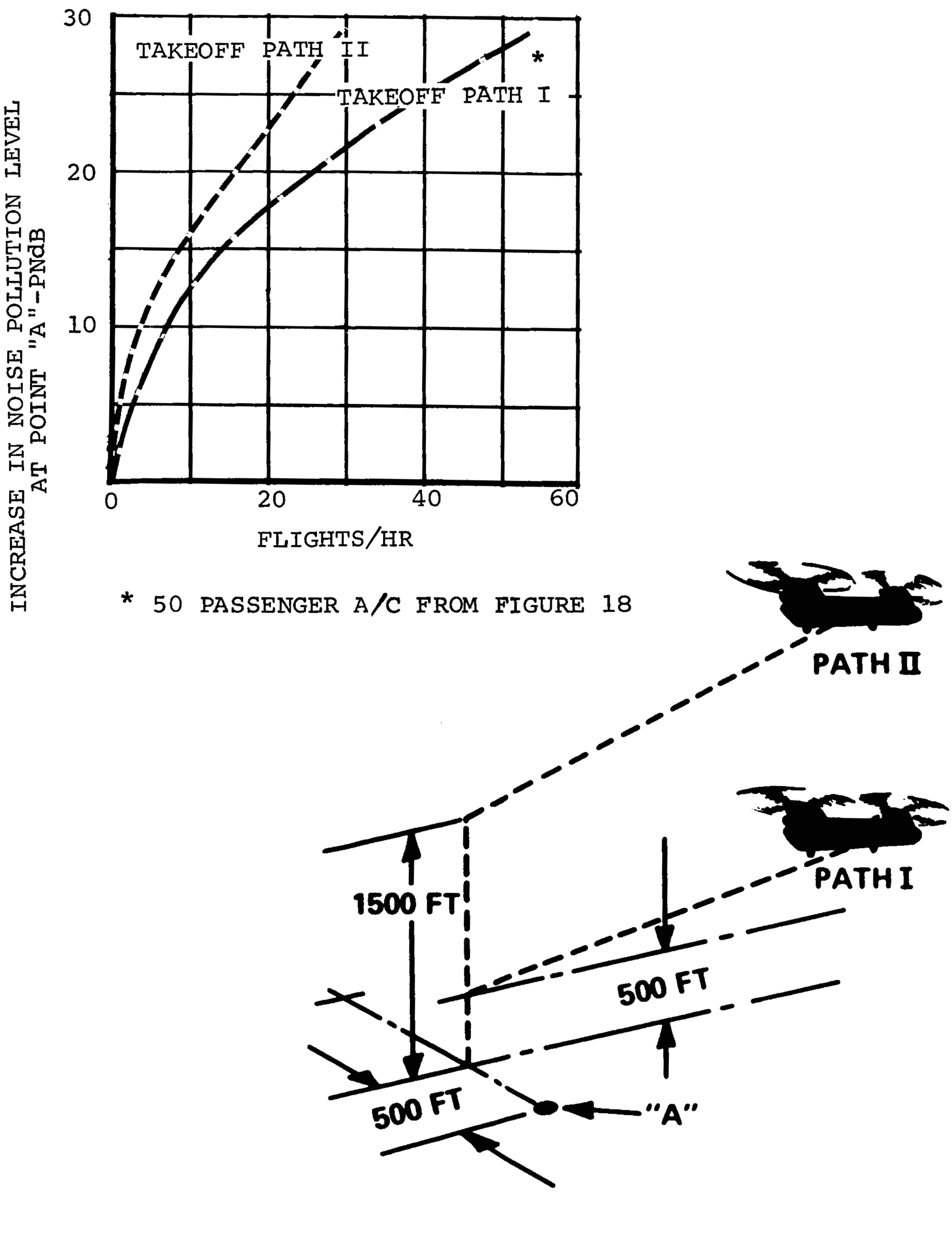


FIGURE 19. Effect of Flight Departure Path

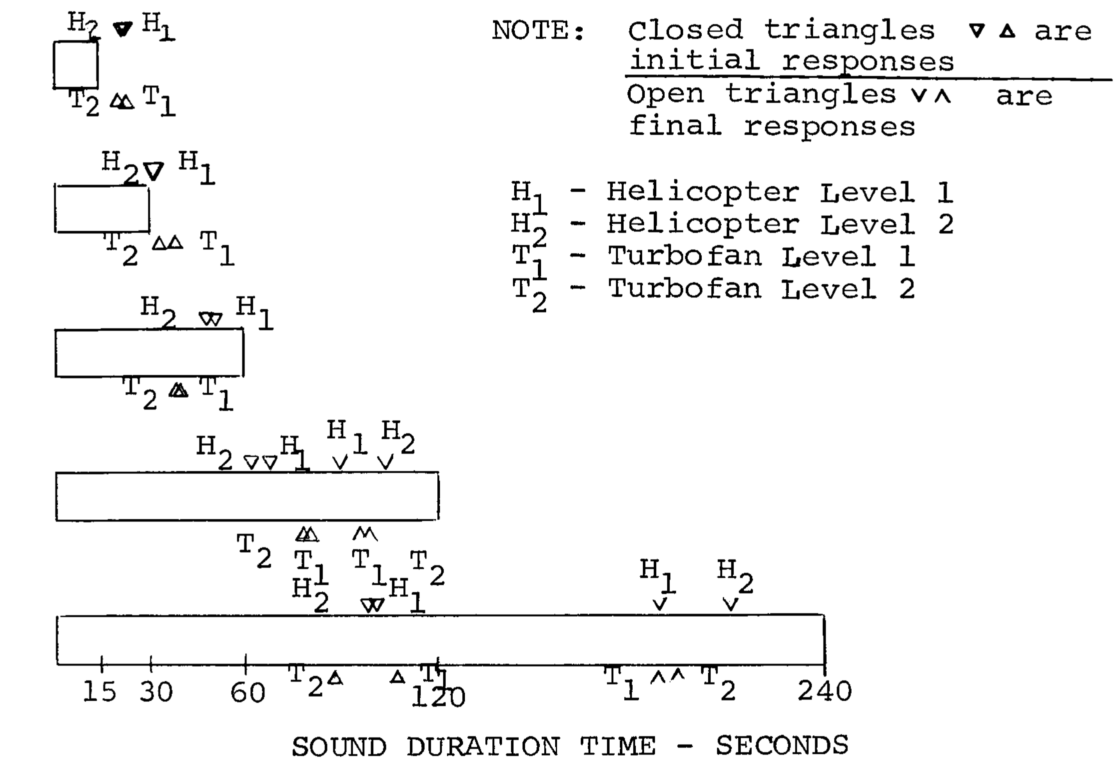


FIGURE 20. Correlation of Response Time with Exposure Time

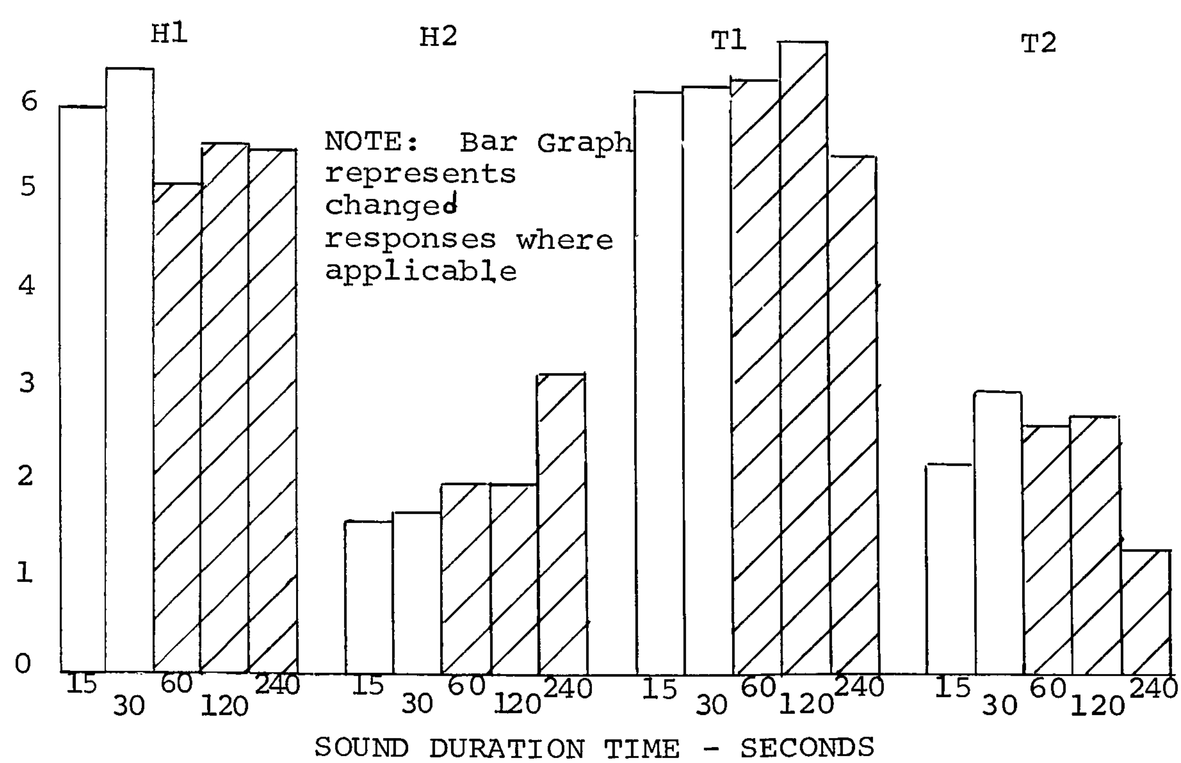


FIGURE 21. Correlation of Noise Rating with Exposure Time

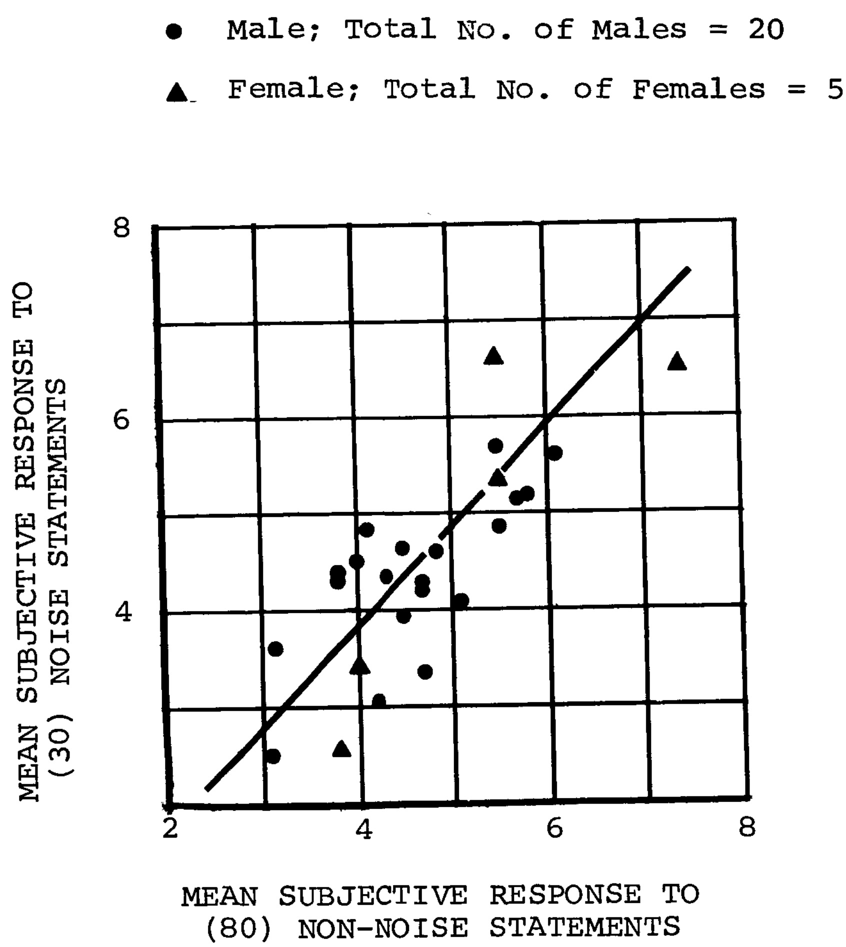


FIGURE 22. Correlation Between Noise and Non-Noise Items on Annoyance Survey